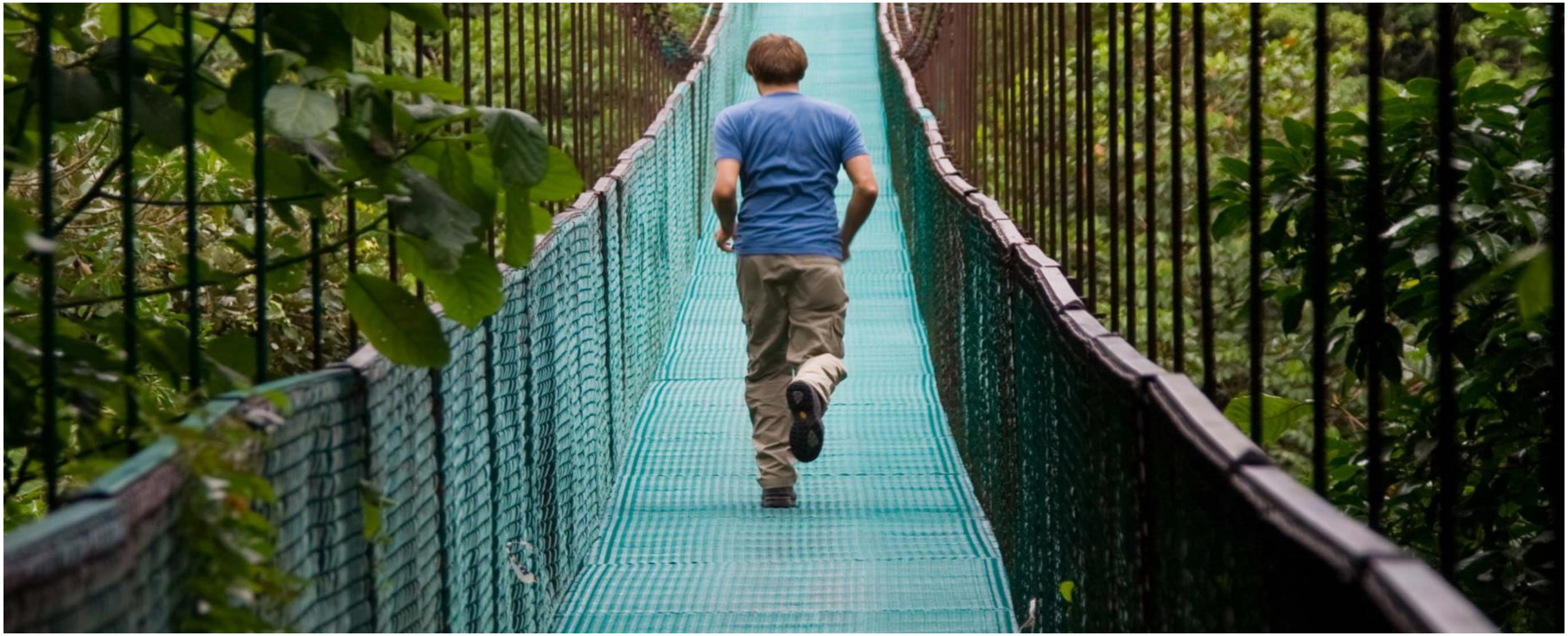


Lean Six Sigma Green Belt

Introduction Module

by
Rajiv Purkayastha
Lean six sigma MBB

Expectations & Objectives-

Objectives

- In this course, Participants will
  - Learn Six Sigma tools applicable to the industry
  - Practice application of Six Sigma tools
  - Enhance readiness for applying Six Sigma concepts within the organization

Competitive Environment

Western Technology

Japanese Quality

Industry

Chinese Prices

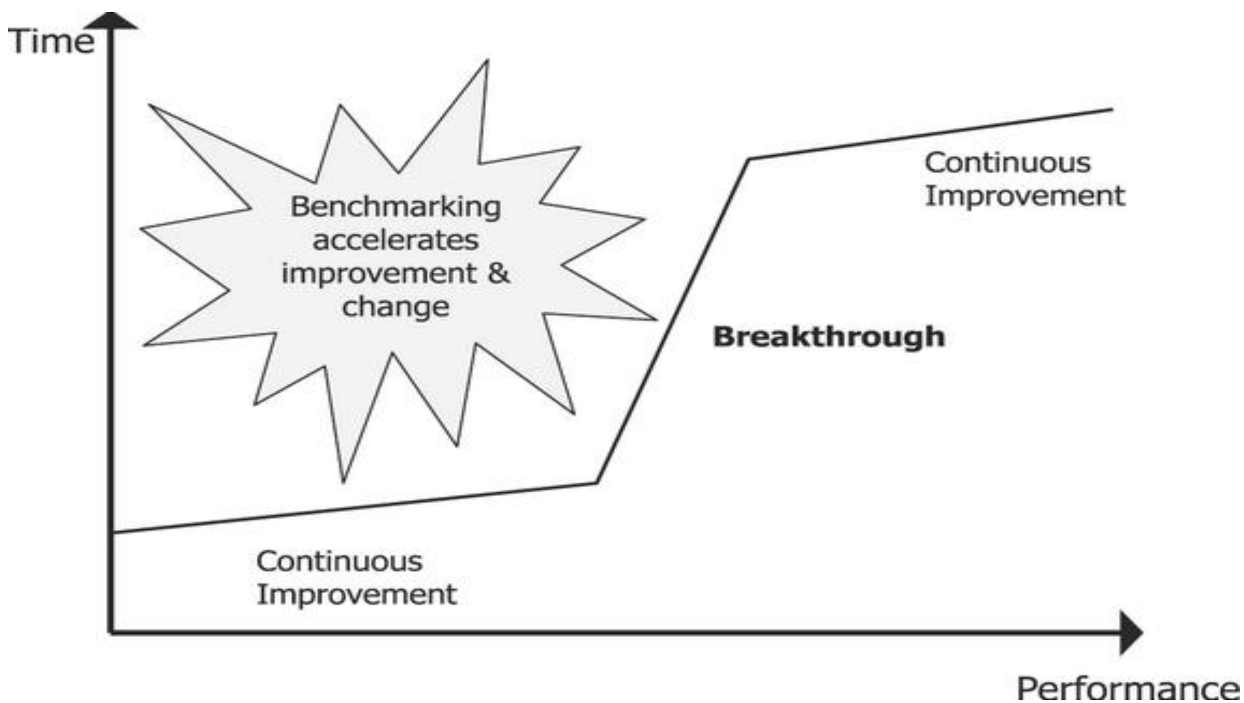
Domestic Competition

Overview of Six Sigma

What do we need to do?

Make large breakthrough improvements to -

- Reduce cost
- Improve Quality
- Faster Delivery



What is Six Sigma ?

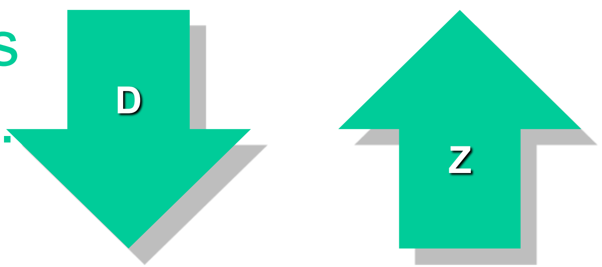
- Measure of Quality
- Process For Breakthrough Improvement
- Enabler for Culture Change

What is Six Sigma ?

Six Sigma is a process driven methodology that uses statistical analysis to drive breakthrough improvements & reduce inherent variability.

- *The term "**sigma**" is a statistical term that measures how far a given process deviates from perfect .*
- *For a business /manufacturing / transactional / service process, the **sigma capability (z-value)** is a metric that indicates how well that process is performing. The higher the sigma capability, the better.*

As defects go down...



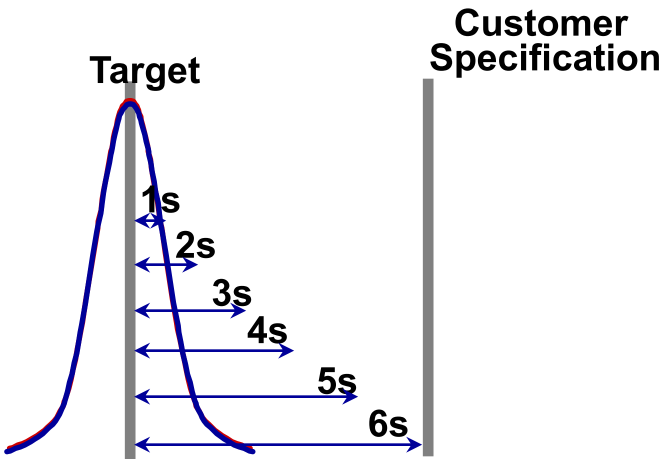
...the Sigma capability ***'Z'*** goes up

What is Six Sigma ?

Six Sigma is

- Measure of Quality
- Process For Breakthrough Improvement
- Enabler for Culture Change

- Six Sigma means = 3.4 defects per million opportunities
  = 99.9996% accuracy



What is Six Sigma ?

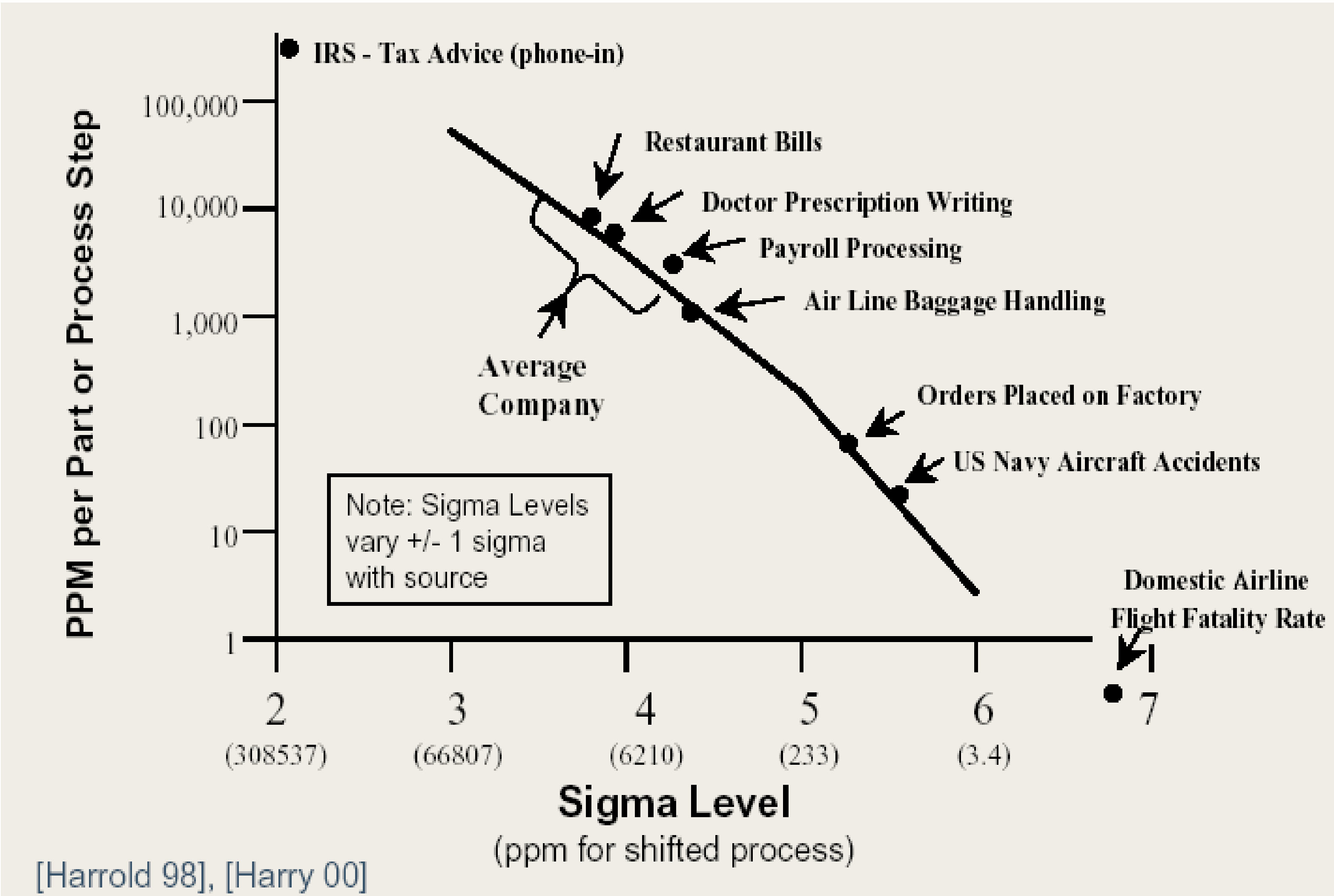
Is 99% accuracy is good enough ?

Which is the World‟s busiest Airport? Hartsfield-Jackson Atlanta International Airport

How many flights does it handle everyday? Approximately 1000

99% Good (3.8 Sigma)	99.99966% Good (6 Sigma)
Ten short or long landings daily	One short or long landing every 2.7 years
Unsafe drinking water for 15 minutes each day	One unsafe minute every seven months
No electricity for almost seven hours each month	One hour without electricity every 34 years
1 incorrect surgical operation per 100	3.4 incorrect operations per million

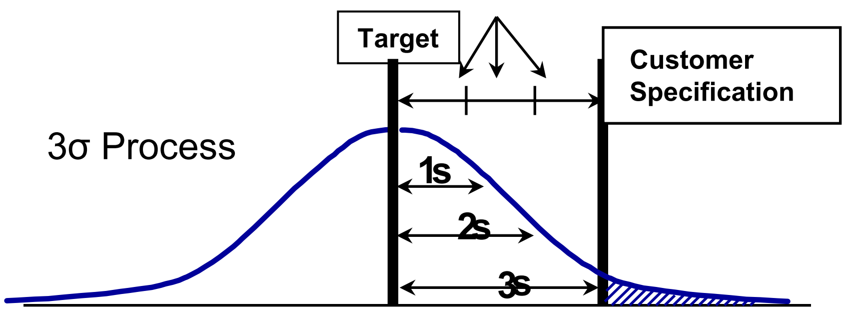
σ Level Across industries



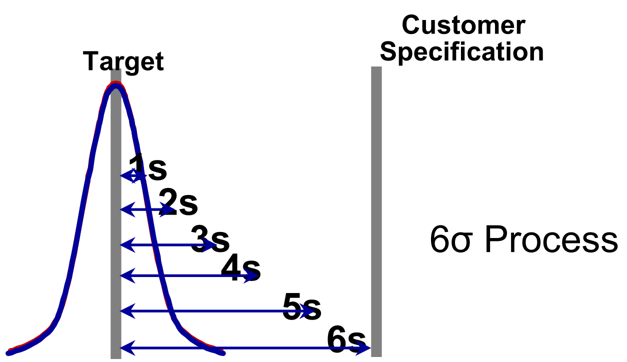
What is Six Sigma ?

- Measure of Quality
- **<u>Process For Breakthrough Improvement</u>**
- Enabler for Culture Change

- Process For Breakthrough Improvement
  - 6 Sigma provides a process based approach for Breakthrough & continuous improvement.
  - It is independent of the measurement involved & can be used to improve any business process

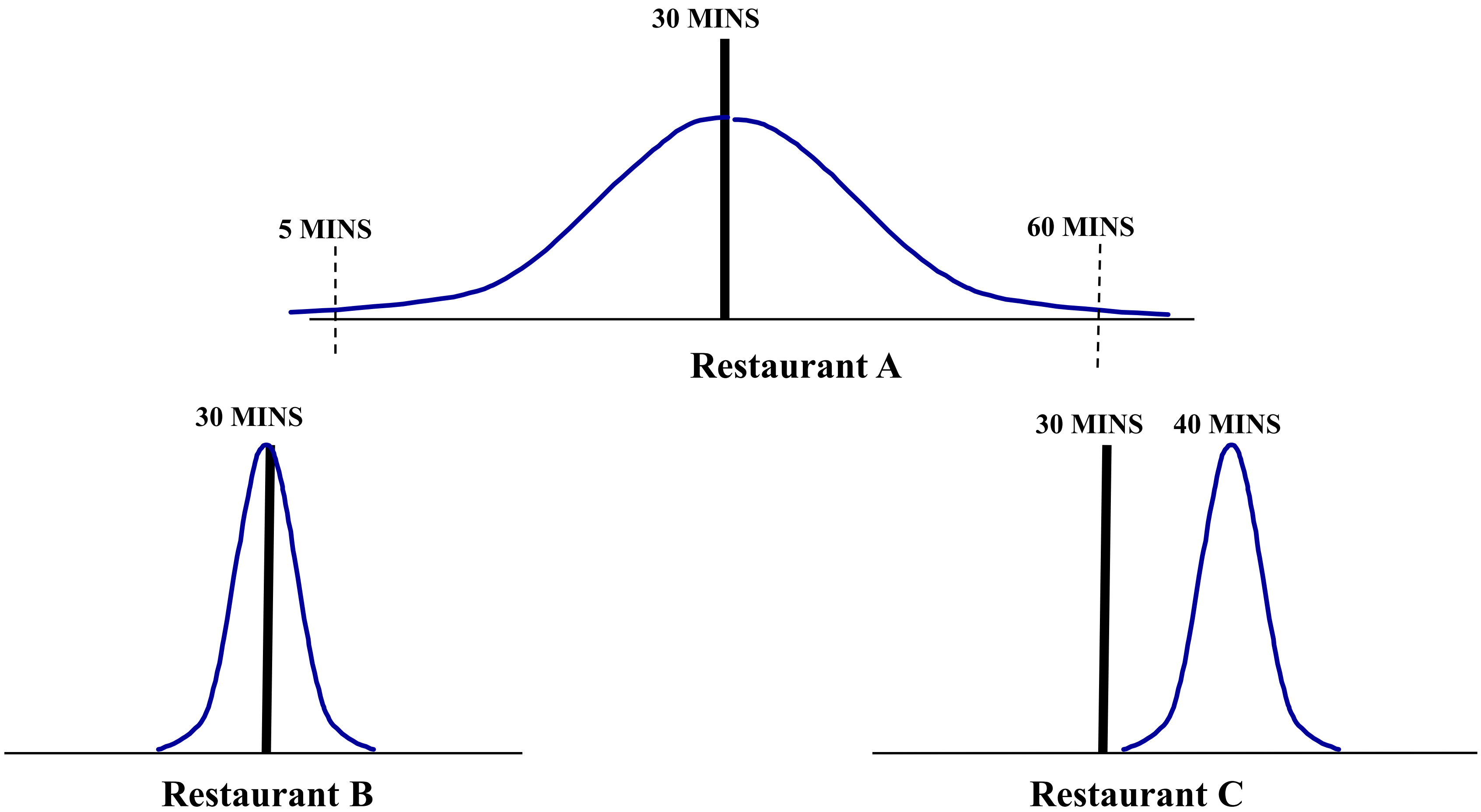


Before



After

An Exercise



Which Process is better & why?

What is Six Sigma ?

- Measure of Quality
- Process For Breakthrough Improvement
- **Enabler for Culture Change**

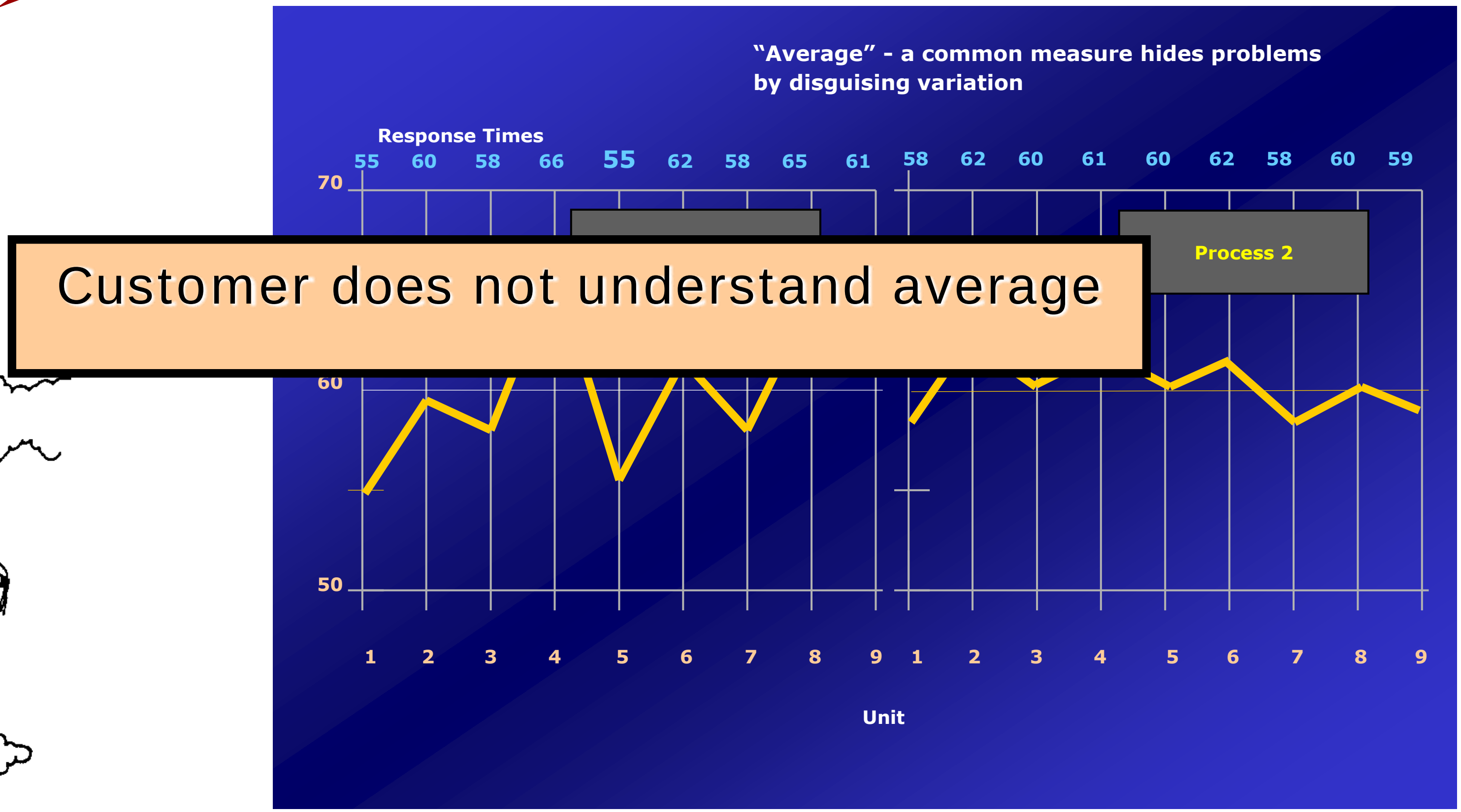
- **Enabler for Culture Change**
  - Six Sigma requires a change in the way any organization works
  - Driven from top

The Difference Six Sigma brings,

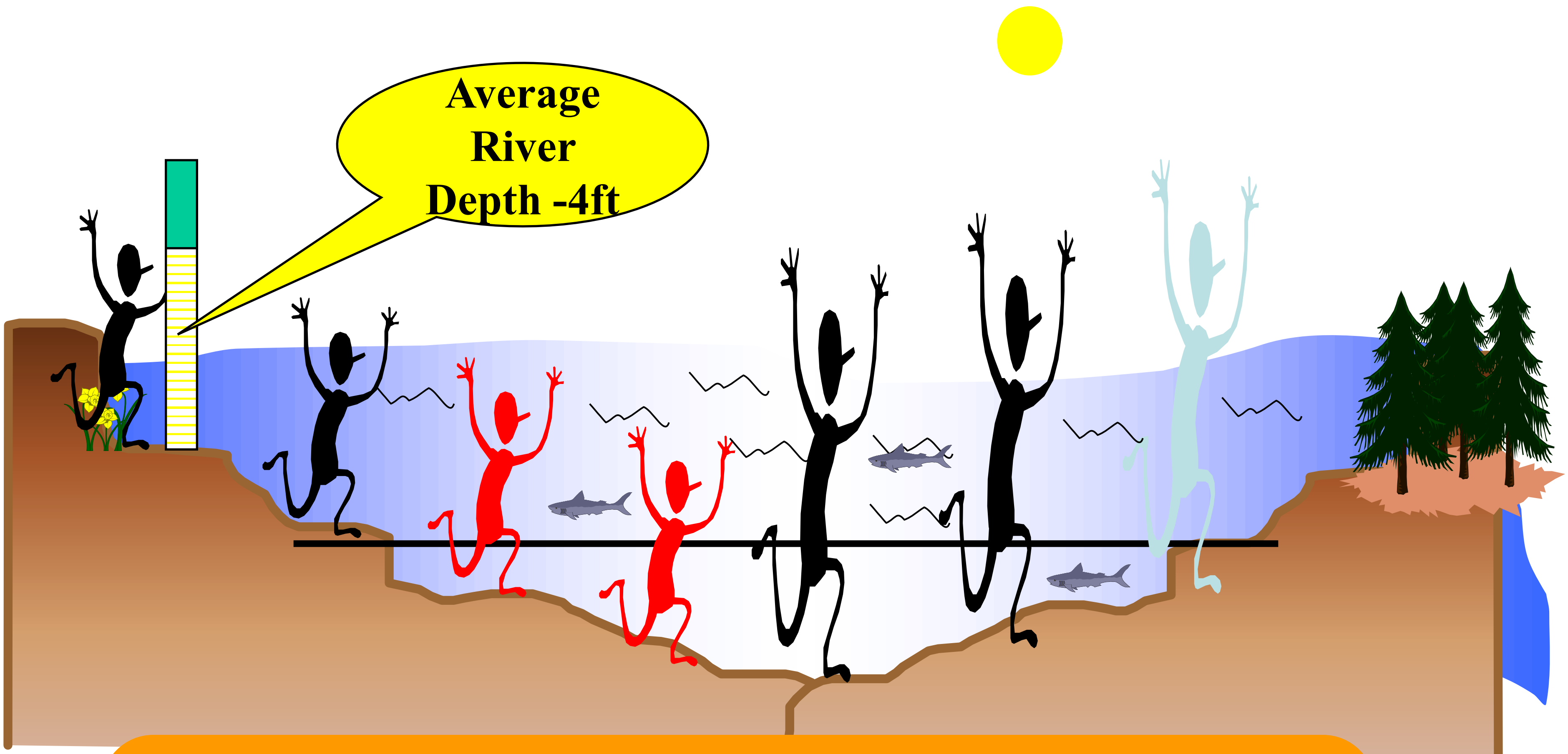
- Driven by the Customer requirements
- Pays attention to Total Business
- Focuses on the Processes
- High on Methodology & Data
- Looks Forward as well as Backward
- High on People
- Aims for Optimal solution rather than what‟s simply „good enough‟

Understanding Variation

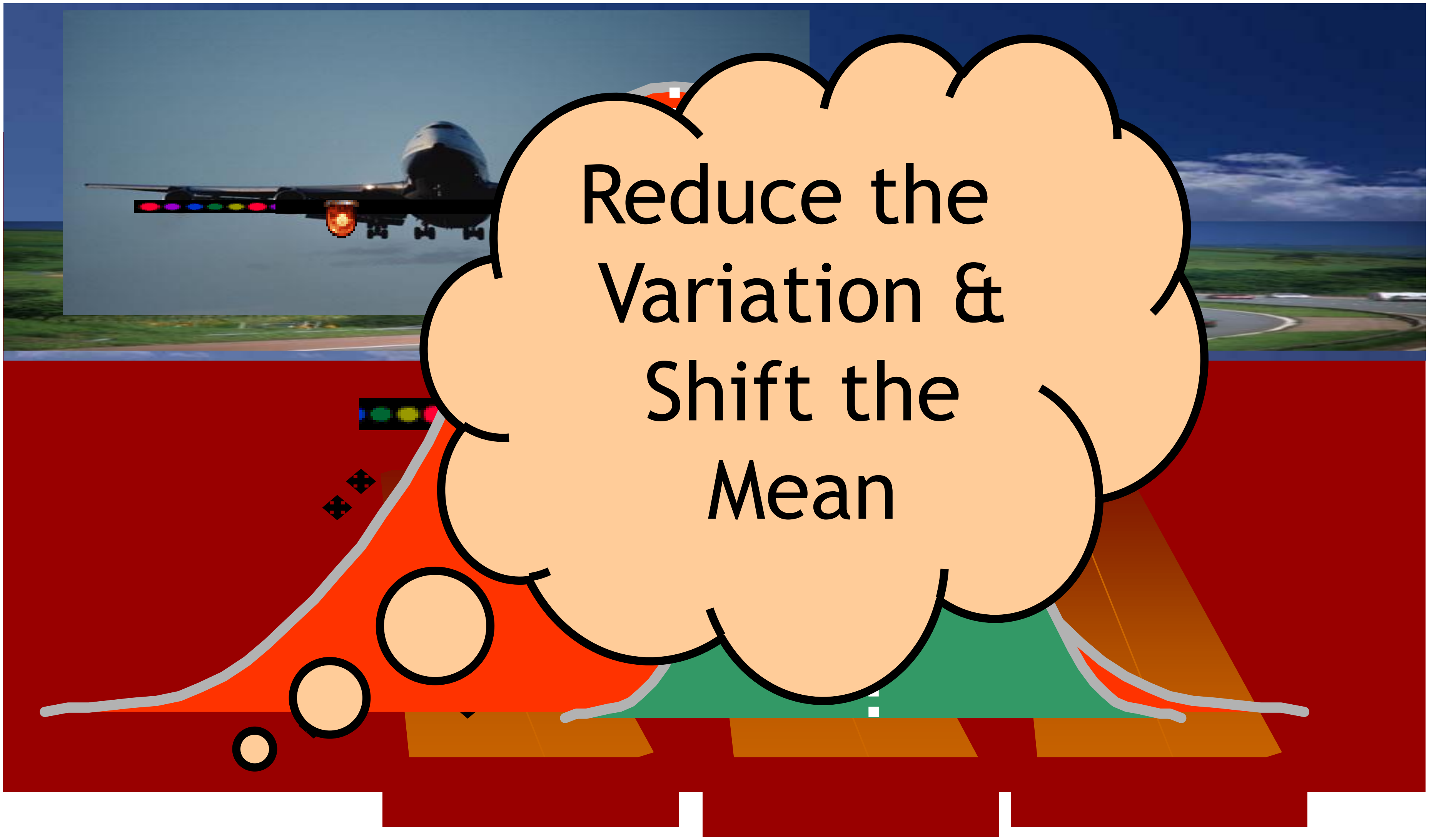
Understanding Variation



Understanding Variation

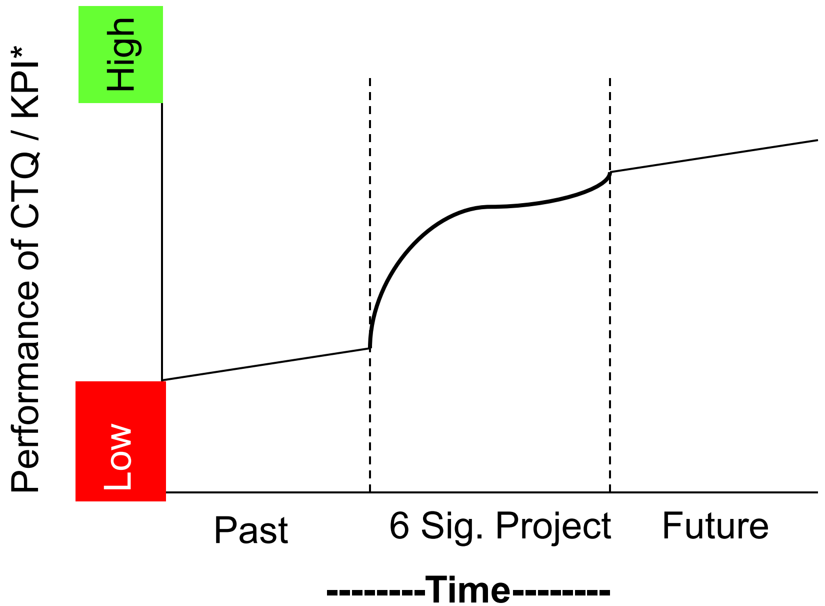


Focus on Average can turn any business "Red"


Reduce the
Variation &
Shift the
Mean

What is Six Sigma ?

Six Sigma is a project based improvement methodology



* KPI : Key performance indicator
CTQ : Critical to quality

The unit of Six Sigma deployment in an organization are Six Sigma Improvement Projects which are executed by task force like teams for a duration of 3-6 months and results in accelerated development of the KPI / CTQ.

"“All improvement takes place project by project, and in no other way.”
-Joseph M. Juran (1904-2008)
American Quality Guru

In a full- fledged Six Sigma deployment , large number of improvement projects run concurrently in the organization bringing in dramatic improvement .All projects must address a CTQ (based on customer voice) or CTP (driven by business voice).

Six Sigma Methodology

To achieve and sustain this accelerated improvement , Six Sigma uses "D – M – A – I – C" methodology

D	Define Opportunities
M	Measure Performance
A	Analyze reasons for defects
I	Improve Performance
C	Control Performance

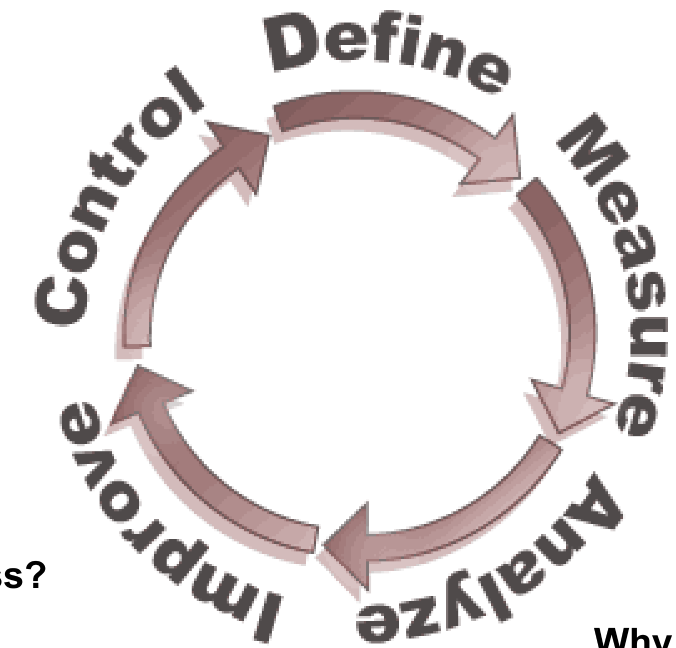
- Focus on "real problems" directly related to enterprise strategy
- Realize results in 3-6 months
- Utilize multiple tools and techniques, especially statistics
- Sustain improvements over the long-term
- Disseminate improvement throughout the organization
- Facilitate customer-focused change

Six Sigma Overview: DMAIC Approach

An Iterative Process For Making Improvement…

What are customer expectations of the process?

How can we make the process stay fixed?



What is my current capability?

How can we fix the process?

Why, when and where do defects occur?

6-Sigma process is 20,000 times better than 3-Sigma Process

Sigma Reported	DPMO*
1.0	697,672.1
2.0	308,770.5
3.0	66,810.6
4.0	6,209.7
5.0	232.7
6.0	3.4

19,650 X Improved

10.75 X Improvement

26.69 X Improvement

68.44 X Improvement

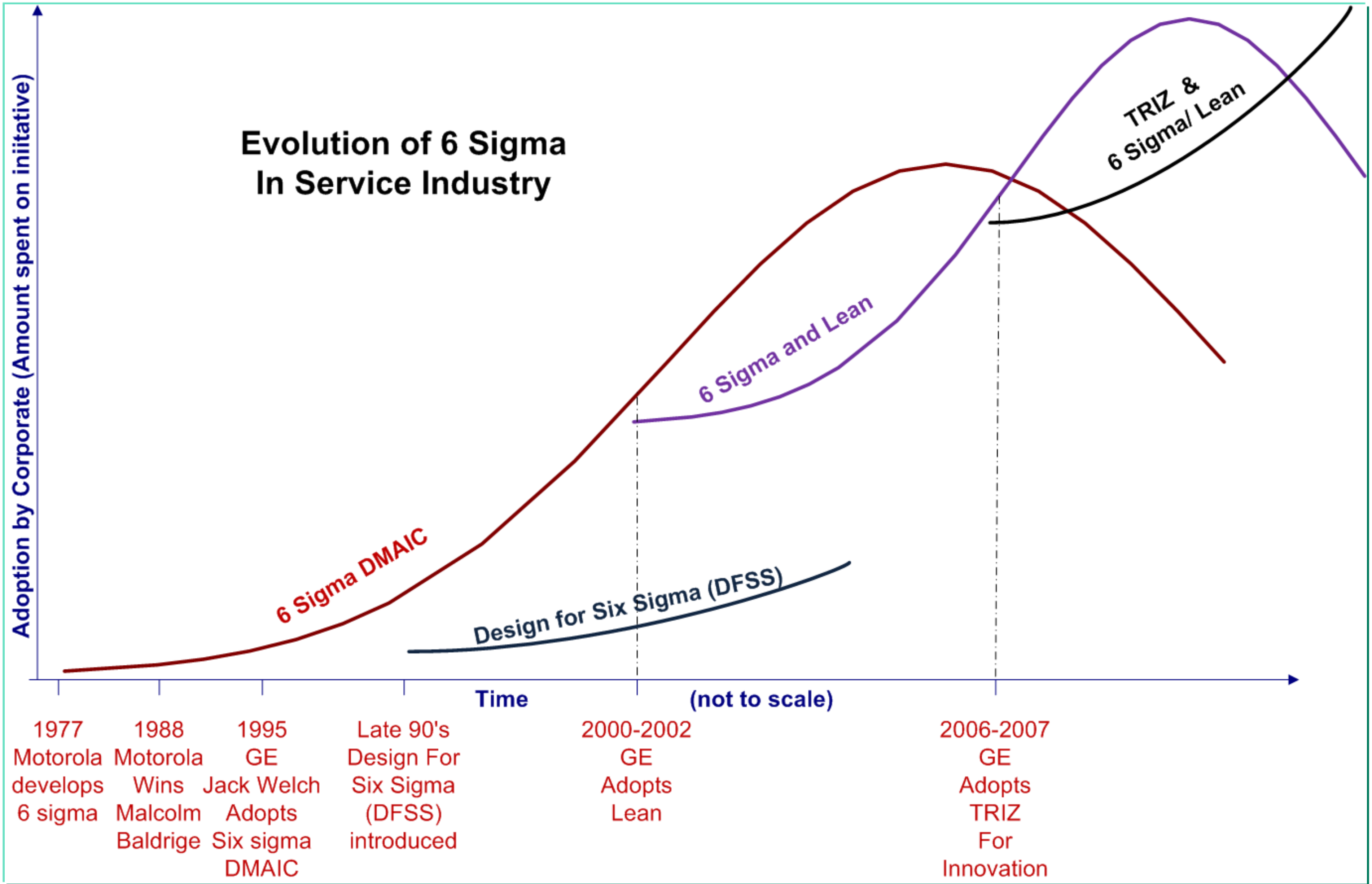
A 6 Sigma Process/Product is 20,000 Times Better to a 3 Sigma

Six Sigma Concept

Six Sigma Means 3.4 Defects in a million Opportunities

1.0σ	697,692 DPMO	30.23% Yield
2.0σ	308,770	69.12%
3.0σ	66,807	93.32%
4.0σ	6,209	99.379%
5.0σ	233	99.9767%
6.0σ	3.4	99.999666%

Six Sigma Evolution


Evolution of 6 Sigma
In Service Industry
Adoption by Corporate (Amount spent on initative)
6 Sigma DMAIC
Design for Six Sigma (DFSS)
6 Sigma and Lean
TRIZ &
6 Sigma/ Lean
Time
(not to scale)
1977
Motorola
develops
6 sigma
1988
Motorola
Wins
Malcolm
Baldrige
1995
GE
Jack Welch
Adopts
Six sigma
DMAIC
Late 90's
Design For
Six Sigma
(DFSS)
introduced
2000-2002
GE
Adopts
Lean
2006-2007
GE
Adopts
TRIZ
For
Innovation

Origin and Evolution of Six Sigma

- **1981**
  - Introduced by Motorola in response to Japanese competition
- **1986**
  - Bill Smith, a senior engineer & scientist at Motorola‟s communications division introduces the concept, crafts the original statistics & formulas, standardizes the way „defects‟ are counted in response to increasing complaints from the field sales force about warranty claims
  - Bob Galvin, CEO, Motorola makes it the way to deliver products
- **1988**
  - Motorola wins Malcolm Balridge National Quality Award
  - Shares the methodology
- **1993-94**
  - ABB, Texas Instruments, Allied Signal embark on journey

Origin and Evolution of Six Sigma (cont)

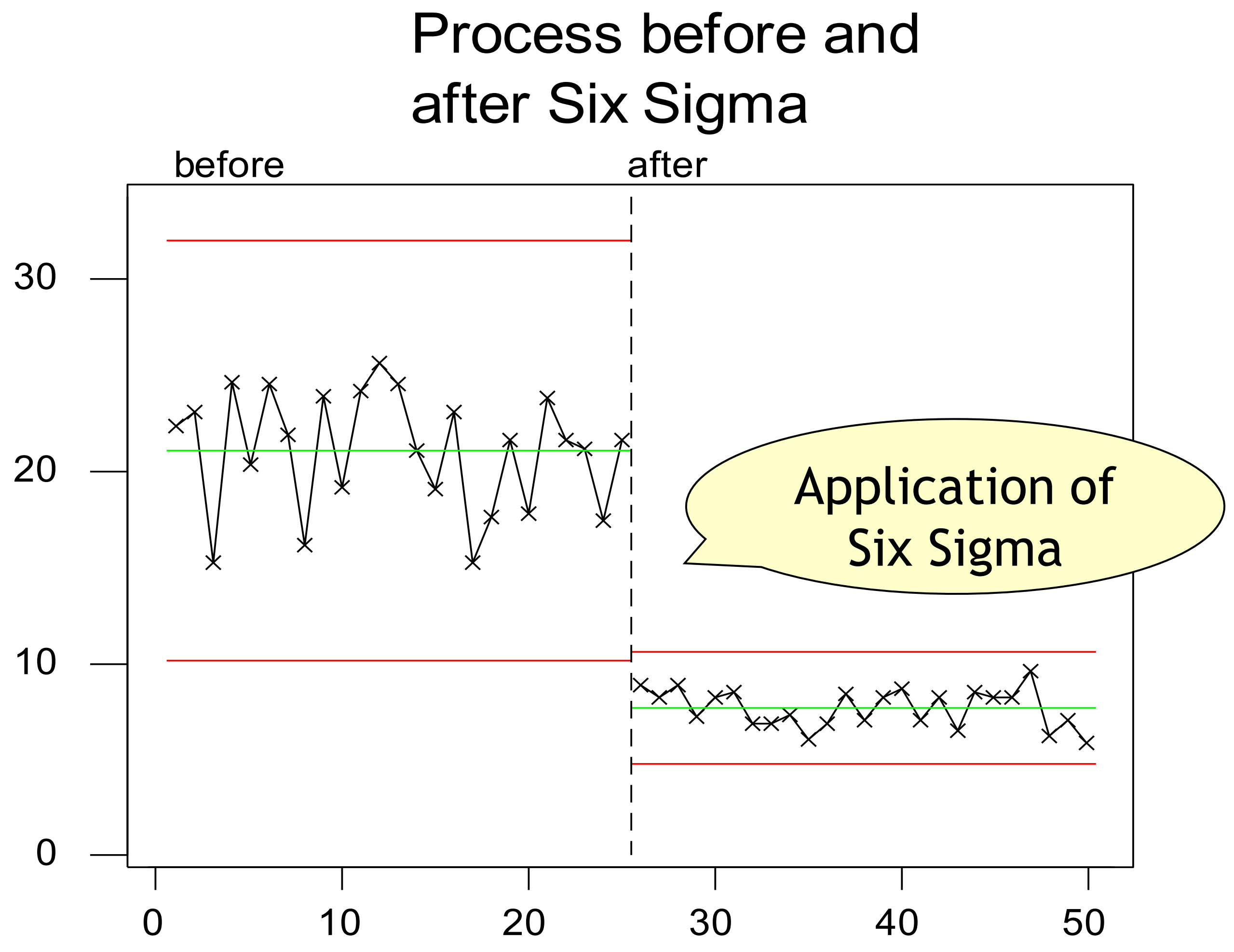
- **1995**
  - Allied Signal CEO Larry Bossidy persuades Jack Welch, CEO of GE into Six Sigma
- **1998**
  - Jack Welch reports savings to date of $1 Bln from Six Sigma and predicts savings of $ 6.6 Bln from Six Sigma
- **Late 1990's**
  - Six Sigma finds popularity in fields other than manufacturing, like in service, financial services, supply chain management etc.

Return on Investment

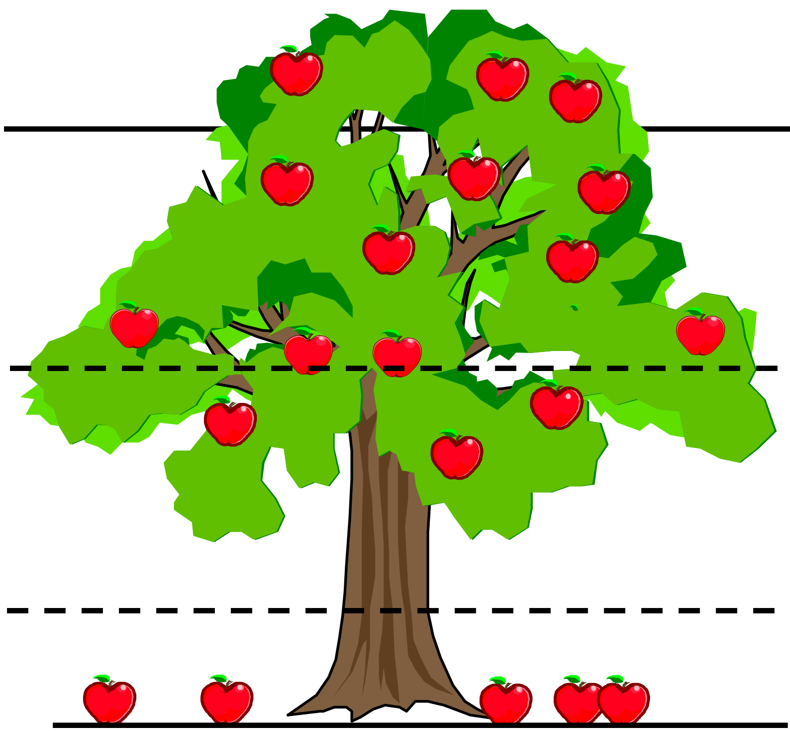
Annual Savings

Savings		**% Turnover**
$1.5 billion	GE	1.4%
$1 billion	MOTOROLA	3.0%
$500 million	AlliedSignal	3.3%
$600 million	Honeywell	2.6%
$300 million	TEXAS INSTRUMENTS	3.3%
$85 million	Seagate	1.3%

Impact of Six Sigma Approach



Six Sigma : Harvesting the fruits



Sweet Fruit

Design for Six Sigma (DFSS)

5 σ Wall - Must Address Designs

Bulk of Fruit

Process Characterization and Optimization

4 σ Wall - Must Improve Internally

Low Hanging Fruit

Seven Basic Tools

3 σ Wall - Demand Improvement

Ground Fruit

Logic and Intuition

Benefits of Six Sigma

Organisation

- ✓ Process Improvement in every sphere
- ✓ Hard data for every business decision
- ✓ Alignment with customer

6σ

Customer

- ✓ Improved products and services
- ✓ Greater synergy with customer
- ✓ Lower price / faster response

Employee

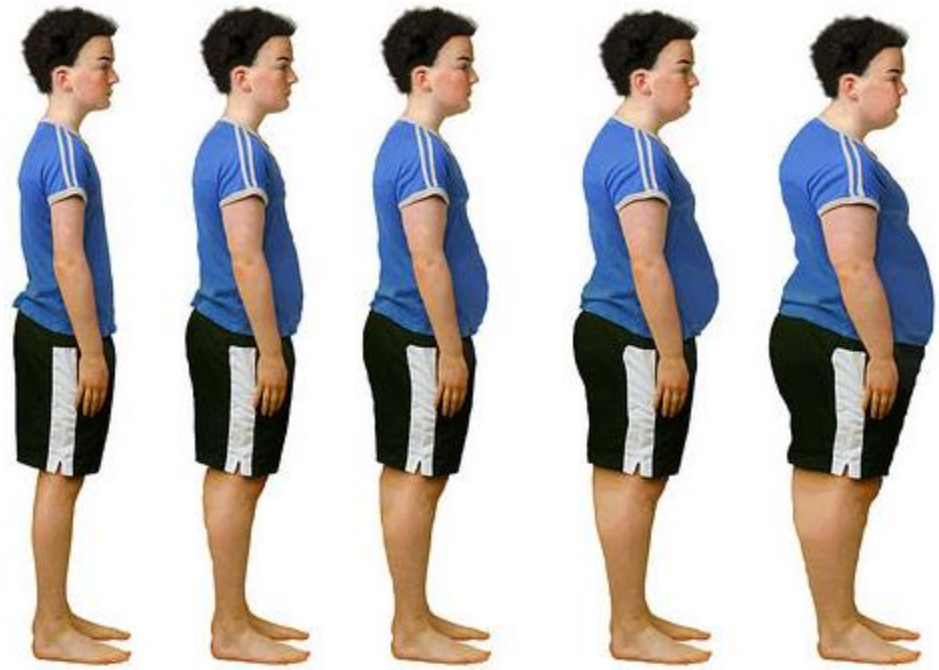
- ✓ Enhanced analytical, communication and presentation skills
- ✓ Opportunity to hone skills in diverse areas of problem solving
- ✓ Career growth through knowledge gain, visibility and certification

"Six Sigma is the only program I've ever seen where customers win, employees are engaged in and satisfied by, shareholders are rewarded, everybody who touches it wins."

Jack Welch, Ex-Chairman of GE

Overview of Lean

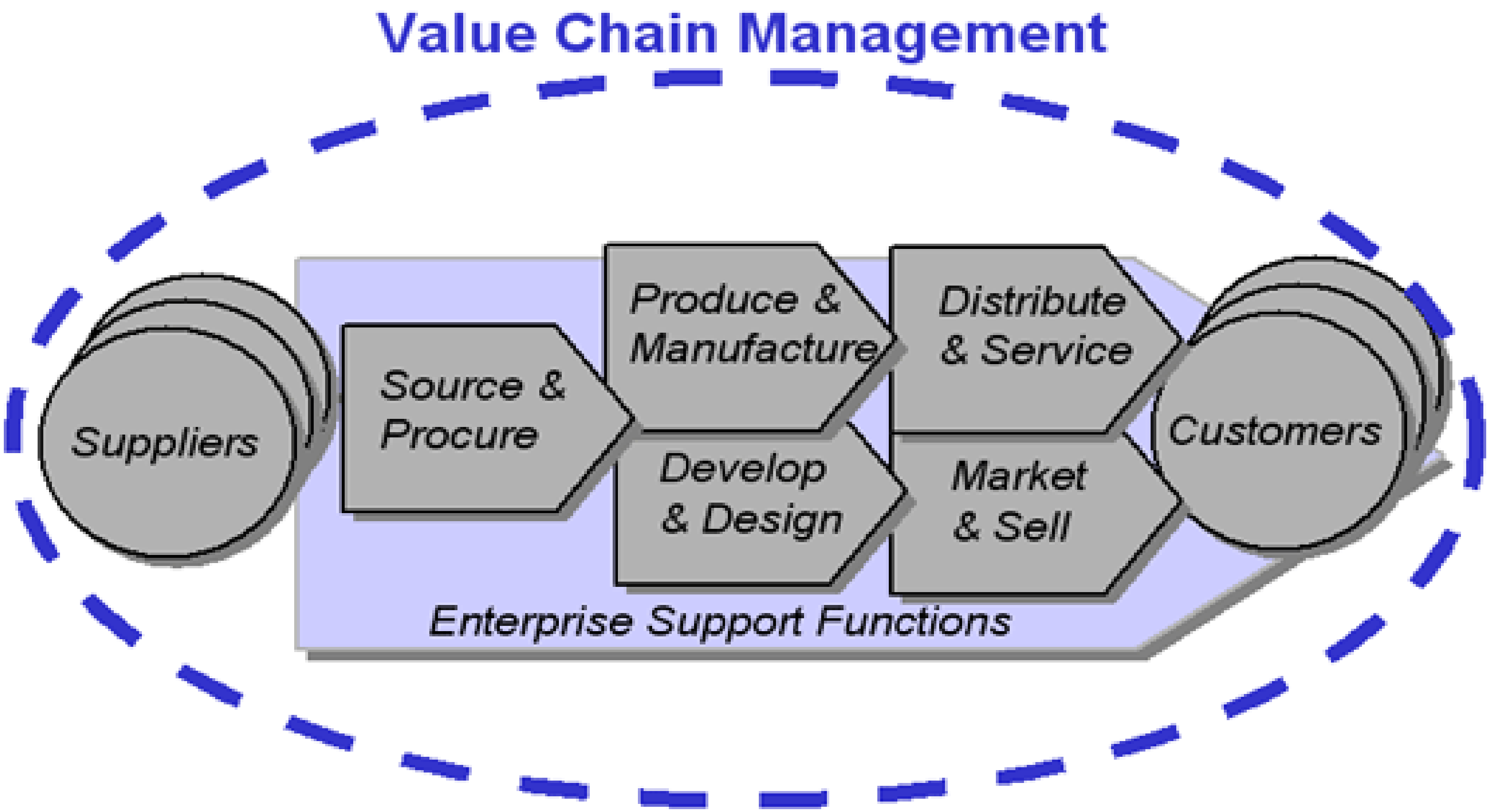
Lean is waste reduction



Remove Waste

Lean Transformation

Covers Transformation of the Entire Value Chain



"Creating the Roadmap for the Future"

The Underlying Premise of Lean

"Time to Cash"

Traditional

Customer Order → Waste → Product Delivery

Time in Value Stream, "Lead Time"

Lean

Customer Order → ~~Waste~~ → Product Delivery

Time in Value Stream, "Lead Time"

✓ **Speed**
✓ **Cost**

A relentless focus on reducing Lead time to reduce costs
. . . by driving out WASTE and SPEEDING up the process

The Theory of Lean

- Let customers say what is of value to them
- Reduce non-value adding activities in the system, causing process speed to increase
- Faster process speed positively relates to less waste, less cost, less work in process (WIP), less complexity, higher quality and happier customers
- Work to eliminate the root causes of the waste and allow for one-piece, continuous flow

Value and Waste

VALUE:

- An activity that transforms or shapes raw material or information to meet customer needs

WASTE:

- Activities that consume time, resources and space, but do not contribute to satisfying customers needs

Customers will pay for value…
they will not pay for waste

All wastes are categorized into 8 types

DOWNTIME (The 8 Wastes, explained)

Defects	• Waste related to poor quality (Supply Chain) • Waste related to mistakes and missed expectations (Back-office, Support functions)
Overproduction	• Producing more product than needed for immediate consumption or customer requirements (Supply Chain) • Performing tasks earlier than needed, pulling resources from higher priorities (Back-office, Support functions)
Waiting	• Product, people, or machines delayed due to earlier processes (Supply Chain) • System elements which cannot perform tasks, due to upstream considerations (Back-office, Support functions)
Not Tapping Potential	• Waste due to not fully utilizing resources available (including human intellect) • Waste related to resisting new ways of thinking or performing functions
Transportation	• Waste related to physical movement of product to different locations (Supply Chain) • Waste related to moving physical or virtual elements across locations (Back-office, Support functions)
Inventory	• Waste related to storing product without specific, current requirements (Supply Chain) • Collecting physical or virtual elements, without actual/immediate need (Back-office, Support functions)
Motion	• Waste related to movement of people or equipment within a task • Waste related to poor ergonomics, or movement within the „envelope‟ of the body
Excess Processing	• Waste related to not understanding actual customer requirements • Performing tasks & functions with greater depth than actually required for the purpose at hand

Benefits of Lean

- Productivity
- Quality
- On-time delivery
- Capacity
- Profit

Upward Trend

Downward Trend

- Cost
- Defects
- Lead time
- Space
- Waste

Lean and Six Sigma : Comparison

Lean	Six Sigma
• Speed and flexibility • Involves all employees • Positive results in short time-frame • Based on industrial engineering principles • Less scientific: Often trial and error	• In-depth root cause analysis and solutions • Builds highly trained and skilled staff • Used for solving more complex, larger issues • Strong, positive results take longer to achieve • Robust infrastructure

- In many cases Improvement projects leverage a combination of Lean & Six Sigma approaches and tools
- Variation, quality problems, hidden x"s? => Six Sigma
- Cycle time, x"s easy to see? => Lean

Lean Six Sigma Vs Traditional Process Improvement Methods

Traditional		Six Sigma
Quality programme	→	Business strategy
Mainly involve quality department	→	Involves everyone, including management
Focus on defects	→	Focuses on processes which create or eliminate defects
Driven by Cost of Quality	→	Driven by Voice of Customer
Focus on training	→	Focus on application - project oriented

What Six Sigma IS NOT ?

- Six Sigma Is Not:
  - NOT A Quality Standard
    - Unlike ISO or COPC or CMMI or..
- Hence:
    - No Rule Books
    - No Global Bodies to Govern it
    - No Audits or Assessments
    - No Particular Target Performance levels

- Which Means: Organization decides
  - When to Use Six Sigma (vis-à-vis other methods & models)
  - Where to Deploy Six Sigma (Which Division, Location.. Etc.)
  - What Six Sigma must focus (Process or Product)
  - What Sigma Level to Target
  - What Pace Should Six Sigma Be Deployed

The Six Sigma Goal

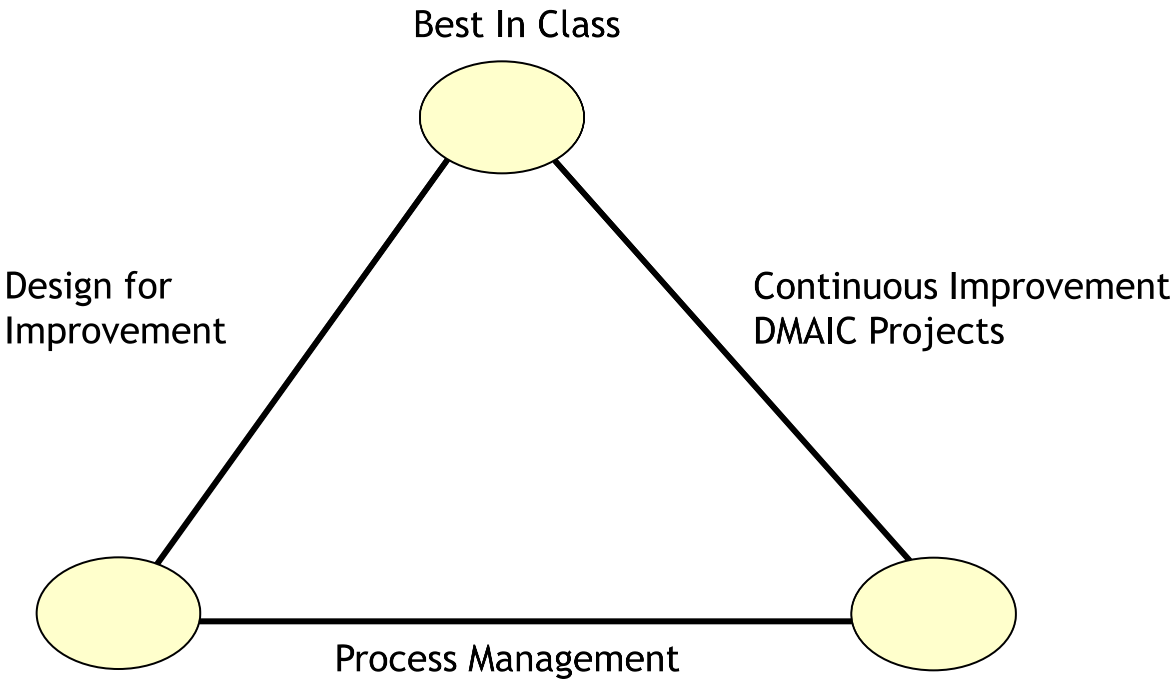
- Because of the use of the sigma terminology, Six Sigma is frequently perceived as a statistics program. This is not the case: Statistics is used solely as a toolset for interpretation and clarification of data
- The focus is on tool selection & application. Use and interpretation of data calculations are left to computers and software

- The ultimate goal is not to produce Six Sigma statistics but companies whose systems and processes are as close to perfection as possible. This is what the ultimate goal of Six Sigma is. This is a cultural revolution and changes the way the organization works!

Six Sigma: Comparison

- What is different in Six Sigma?
  - **Six Sigma project** is typically targeted to a specific characteristic of a product or service and not to the complete product or service. The product or service requirements is typically broken down into smaller and more manageable project areas. These project areas could be initiated for improvement simultaneously.
  - Six Sigma focuses on across the **process improvement** encompassing all operations or functions making it more effective.
  - Six Sigma facilitates creation of process specific goals within an organization from the **customer's perspective**. This forces the organization to critically examine the way processes run. This evaluation ensures that the organization constantly seeks out newer and better ways of working --- be it technology up gradation or process redesign.
  - Six Sigma facilitates **simplification of systems and processes** within an organization ultimately leading to creation of effective control systems to manage

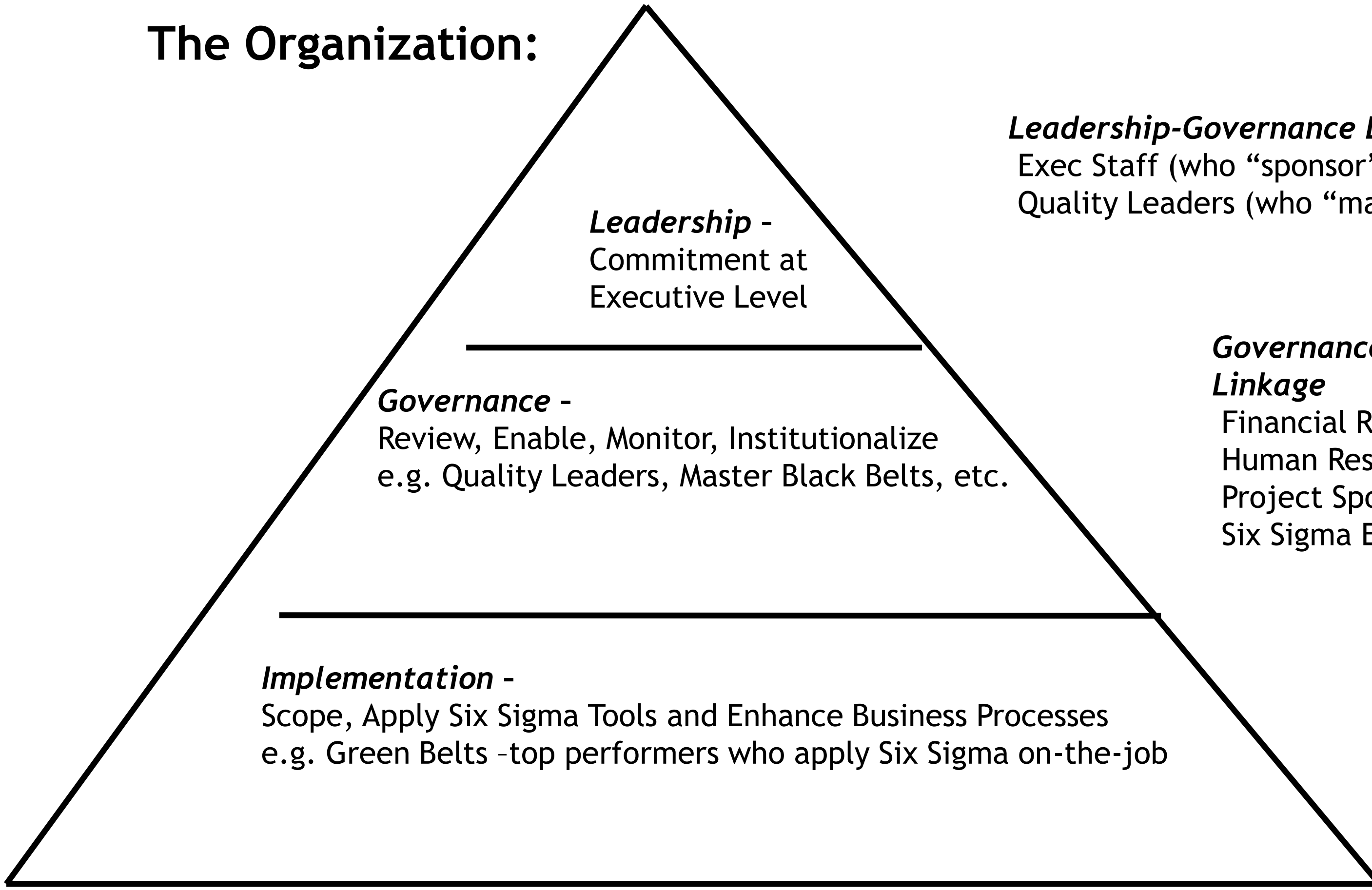
Six Sigma: How does it work



Process Management is the Foundation

Six Sigma: The Organization

The Organization:

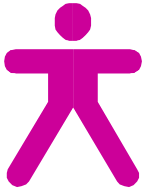


Leadership-Governance Linkage
Exec Staff (who "sponsor" Six Sigma Initiative)
Quality Leaders (who "manage" Six Sigma Initiative

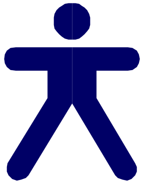
Governance-Implementation Linkage
Financial Reviewers
Human Resources
Project Sponsors
Six Sigma Experts

Investing in dedicated resources

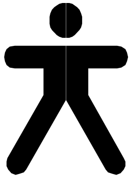
Key Players in Six Sigma Projects



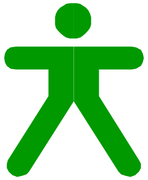
Champions/Sponsors: Trained business leaders who lead the deployment of Six Sigma in their respective business area



Master Black Belts : Fully-trained quality leaders responsible for Six Sigma strategy, training, mentoring, deployment and results



Black Belts : Fully-trained Six Sigma experts who lead improvement teams, work projects across the business and mentor Green Belts



Green Belts : Fully-trained individuals who apply Six Sigma skills to projects in their job areas

Yellow Belt Individuals who receive specific Six Sigma training and who support projects in their areas

Six Sigma: The Roles in the Organization

- Quality Leader:
  - Cascade Customer Needs into Business Imperatives
    - Develop & Deploy
      - Operational Effectiveness Measures
      - Continual Improvement Culture
- Master Black Belt:
  - Identify Areas of Improvement… drive Change
  - Spin off Projects
    - Mentor them to meet goals
  - Coach & Train employees in Six Sigma Tools
- Black Belt:
  - Lead Projects… applying the methodology
  - Dedicated Change Agents …18 to 24 Months stint.
  - Coach Green Belts & Mentor GB projects
- Green Belt:
  - Trained in Six Sigma tools…
  - Part time Six Sigma… approx 30-40 % time
  - Does improvement project… in their Process.

Characteristics of an Effective Six Sigma Practitioner (Green Belt)

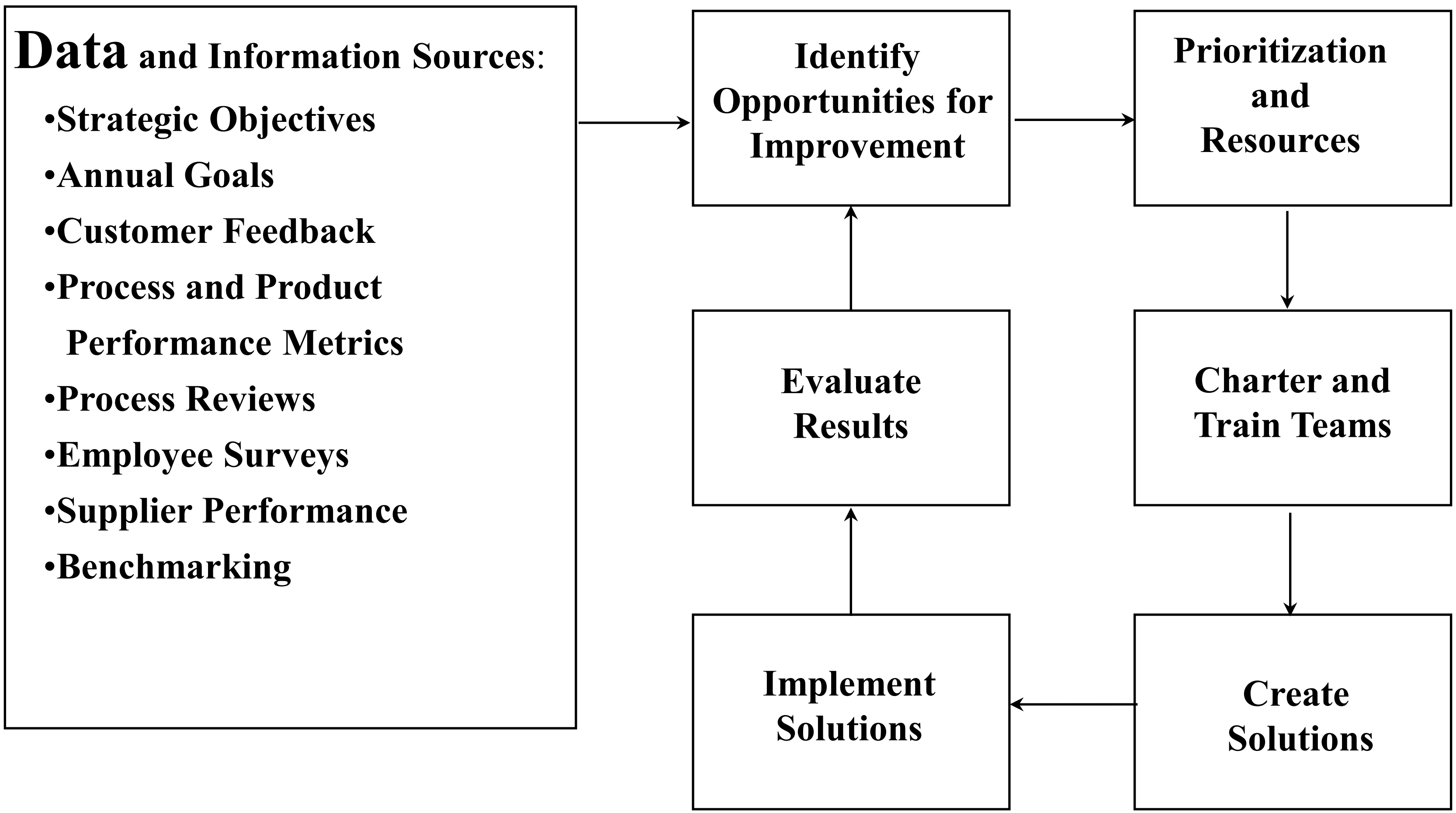
- I Can Do Attitude
- Change Leadership Skills
- Effective Communicator
- Understanding of the Business
- Project & Stakeholder Management
- Technical Aptitude
- Team Player and Leader
- Result Oriented
- Customer Advocacy
- Enjoy & passionate about job

Six Sigma Deployment in Organization – Best Practices Seen

- Typically an organization deploying Six Sigma would have
  - Dedicated and part time resources leading improvement projects
  - Projects is the medium to deploy Six Sigma
  - Typically a percentage (1 to 2%) of the workforce are dedicated with about 5 to 10 percentage workforce, at a given time, being part time resources in Six Sigma
  - Selection of projects is critical, as the projects must be addressing the pertinent issues in the business
  - Senior leadership involvement and participation in project selection is a MUST.

Translating Business Issues to Projects

Improvement Project Portfolio Management



Six Sigma Deployment in Organization Best Practices Seen

- **Considerations for project selection**

  1. **The Context**
     1. Customer based: Higher revenue, Improved customer value that drives behavior.
     2. Efficiency based: Lower costs, Higher utilization
     3. Process centric: Repeatability, Reproducibility, Scalability and reliability
     4. Employee centric: Higher employee loyalty, Retention.
     5. Business /Stakeholder / Suppliers centric: Growth, Vendor management, Culture

  2. **Ease to replicate or translate the success across the business**

Six Sigma Deployment in Organization
Best Practices Seen

Considerations for project selection

3. **Associated Risks**
   i. Probability of success: Is it tied to the sponsors‟goal or objective? Realistic time to completion?
   ii. Complexity of the project: More complex lower the probability of success.
   iii. Clarity of the problem and the scope: Can it be articulated in numbers or words?

4. **The Financial perspective**
   i. The benefit to cost estimate.
   ii. Resources requirement - Skill sets required

Prioritization

- Categories used for Issues Prioritization

  1. Risks Involved

  2. Benefits expected

  3. Efforts Required

1. Risks Involved Criteria

1. Gestation period for completion
2. Probability of success
3. Clarity of the Issue
4. Clear Project Boundaries
5. Data availability
6. Domain of Influence
7. Alignment with KRA‟s of the Sponsor
8. …

Hard Day

2. Project Benefits

- **Project Benefits**
  - What about Project Benefits?
    - Have an estimate at this stage
    - Benefits estimates help:
      - Prioritize
      - Motivate
      - Set out the Bottom line focus from start

- **Benefits Criteria?**
  - Be Auditable
    - Documented
  - Incremental
- **What are the Benefit Types?**
  - Hard Benefits/ Tangible Benefits
  - Soft Benefits / Intangible Benefits

Tangible vs Intangible Benefits

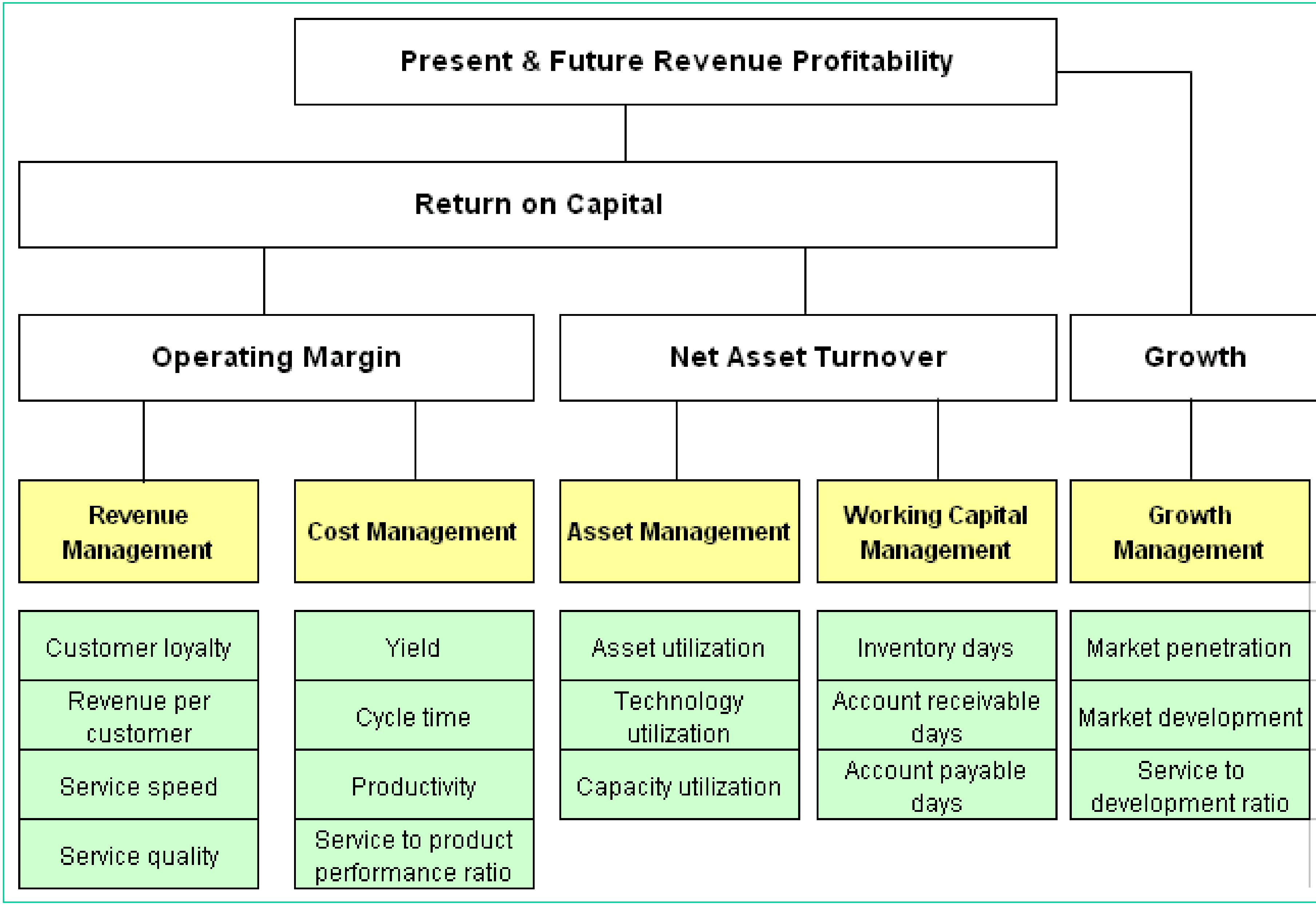
- Tangible Benefits
  1. Rework reduction
  2. Increased utilization or productivity
  3. Lower cost per unit of service
  4. Interest savings
  5. Improved cash flow
  6. Customer retention

- Intangible Benefits
  1. Satisfaction improvement
     - Customer
     - Employee
  2. Improvement in compliance scores
  3. Improvement in employee morale
  4. Other projects making use of project artifacts

Expected Benefits Classification

1. **Bottom-line hard dollar**
   - Decreases existing business costs
   - Takes cost off the books or adds revenues to the books
2. **Cost Avoidance**
   - Avoids, incremental costs that have not been incurred but would have occurred if project were not performed
3. **Lost profit avoidance**
   - Avoids lost sales that have not been incurred, but would have occurred if project had not happened
4. **Productivity**
   - Increases in productivity which improves utilization of existing resources
5. **Profit enhancement**
   - Potential sales increase, which would increase gross profit
6. **Intangible**
   - Improvements to operations of business which can be necessary to control, protect, and/ or enhance company assets but are not quantifiable

Project Selection on Financial Results Basis



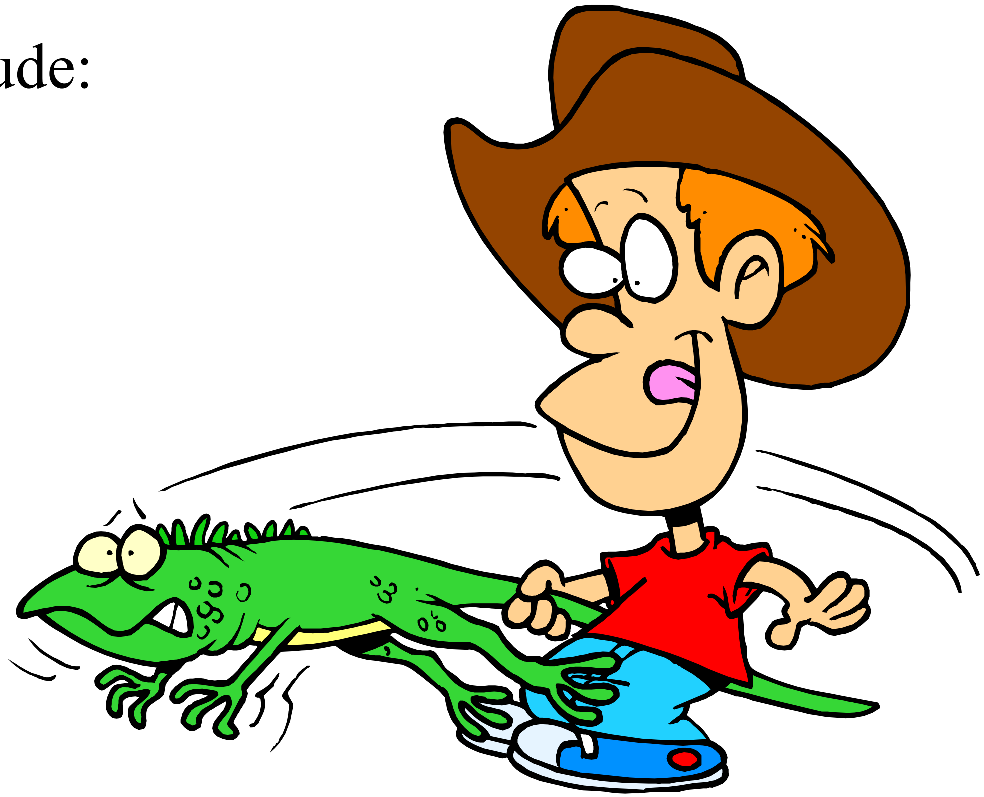
3. Efforts Criteria

- Criteria for Efforts could include:

  1. Complexity of the Issue

  2. Resource required
     i. People
     ii. Hardware/Software

  3. …



Resource Identification Criteria

- Some suggested criteria…

    1. Past Performance
    2. Time Availability
    3. Communication
    4. Process Knowledge
    5. Leadership
    6. Analytic bent
    7. Credibility
    8. …

Reward and Recognition Criteria

- Some criteria…

  1. On Time
  2. Met Goals
  3. Customer Feedback
  4. Financial Savings
  5. Project Management
  6. Leadership demonstration
  7. Complexity of project
  8. Project scope
  9. …

Thanks!!!

What is Six Sigma?

What is Six Sigma?

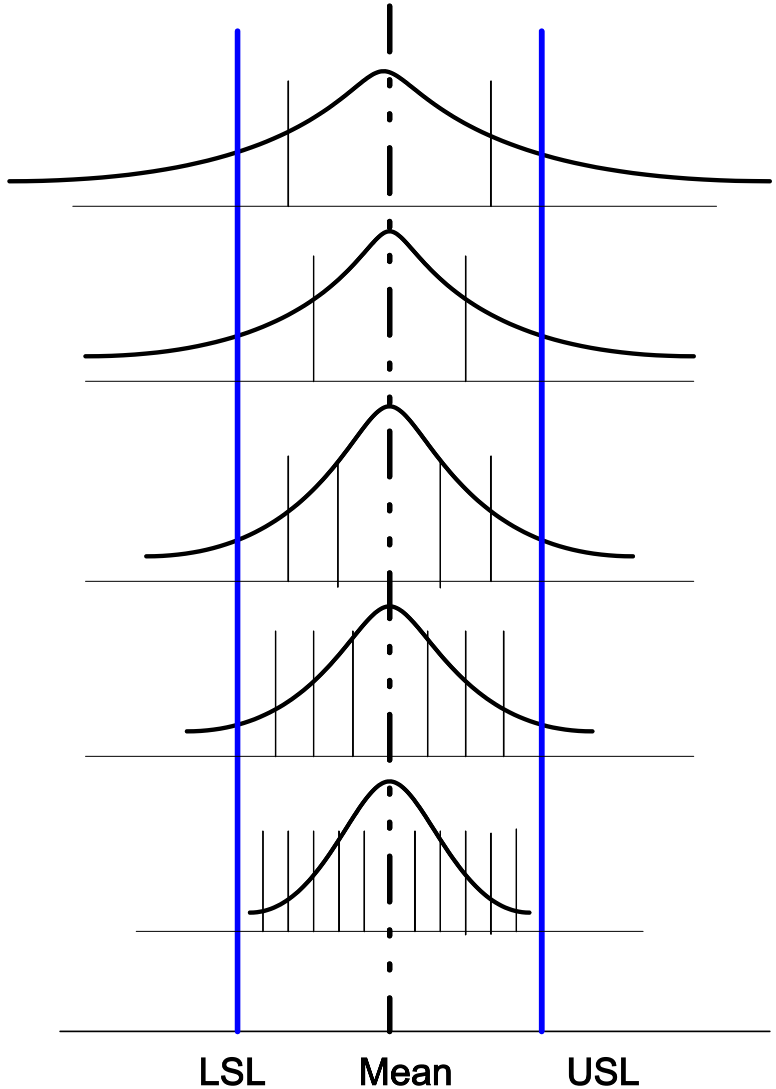
- Six Sigma is a measurement „Yardstick”
  - Determines capability of process
  - Higher capability means lower defect possibility

- Sigma
  - In Statistics represents variation for a process (standard deviation)

- Six
  - Number of standard deviations possible to be fitted between the Mean and the specification
  - When it is at Six we expect no more than 3.4 defects per million opportunities

Six Sigma Concept (cont)

How many Standard deviations can we fit in between the Mean and the Specification Limits?



1.5 Std dev : 1.5 Sigma

2 Std dev : 2 Sigma

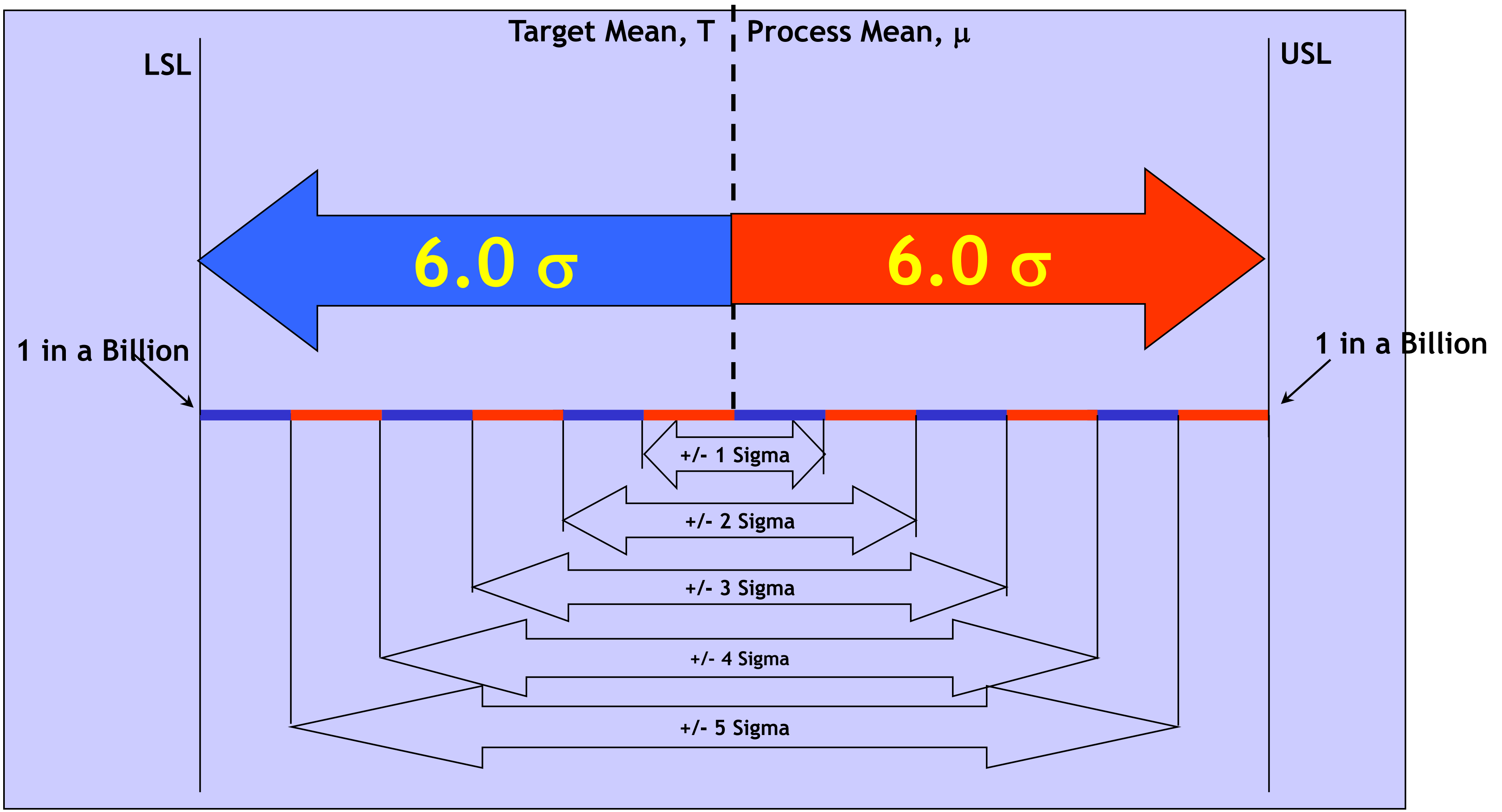
3 Std dev : 3 Sigma

4 Std dev : 4 Sigma

6 Std dev : 6 Sigma

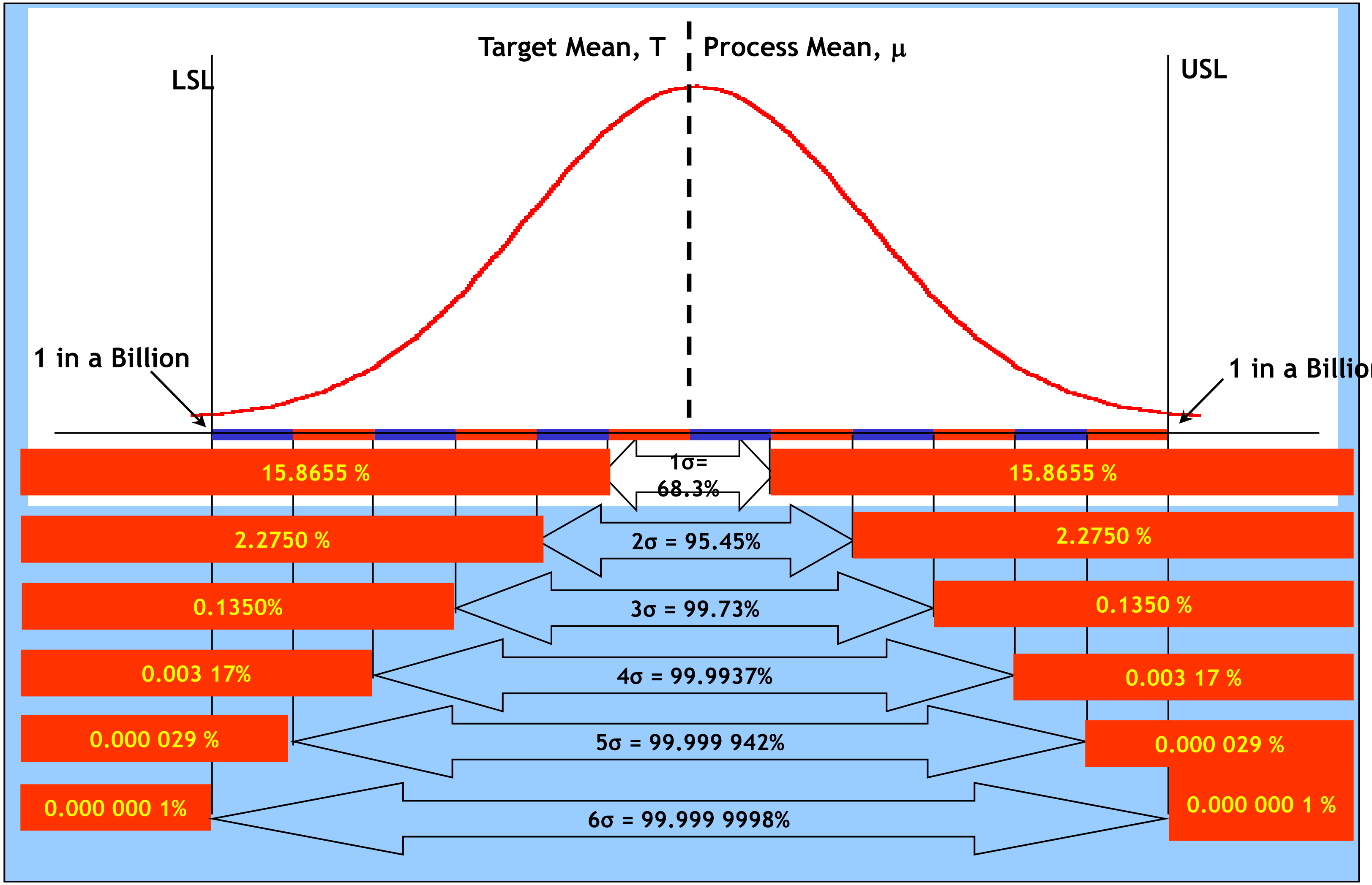
Six Sigma Concept (cont)

Centered Process

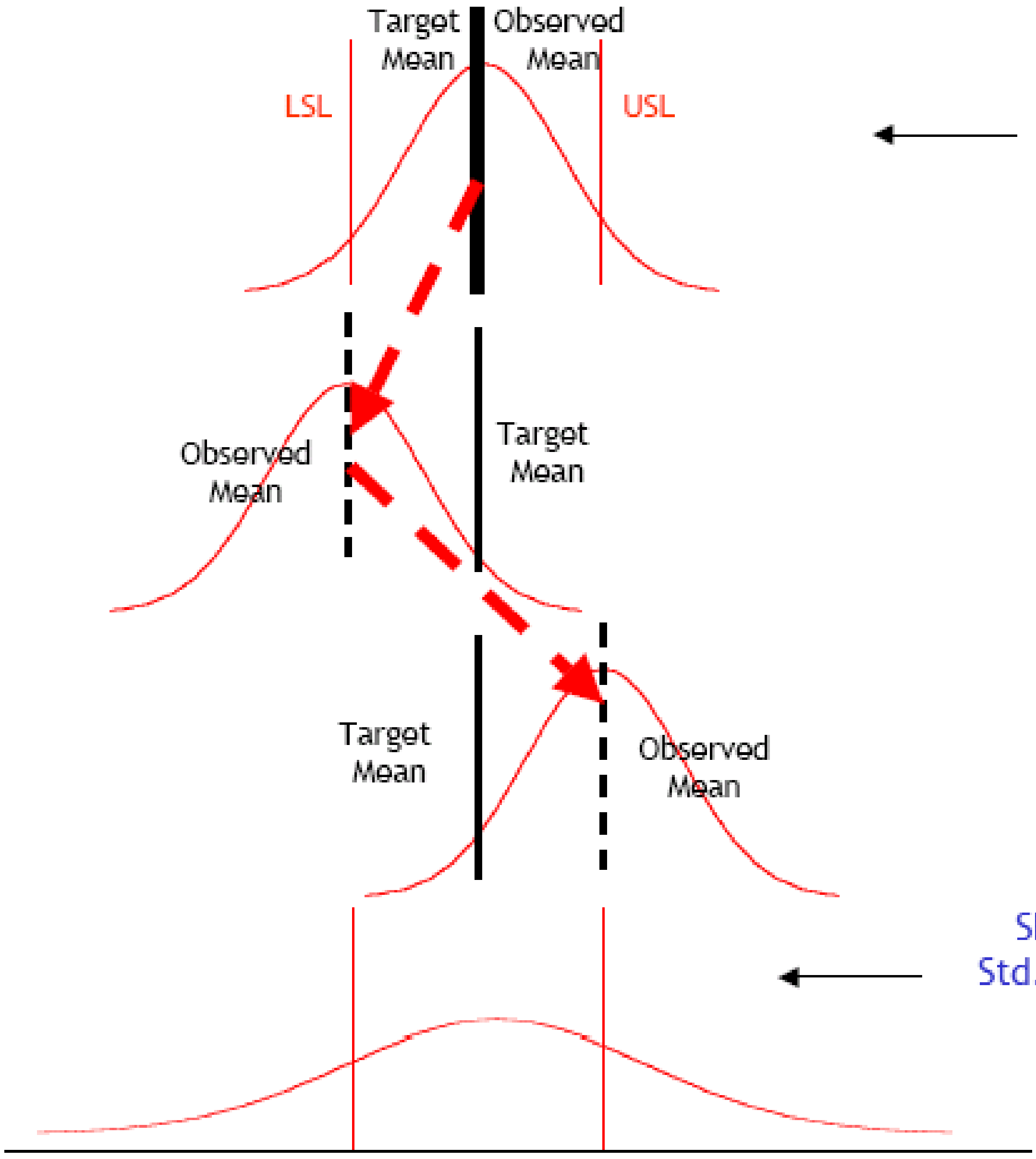


Six Sigma Concept (cont)

Six Standard deviation on either side is 2 Defects in Billion NOT 3.4 in Million



Shift and Drift over Time



In Short Term
Lower Deviation
And Hence:

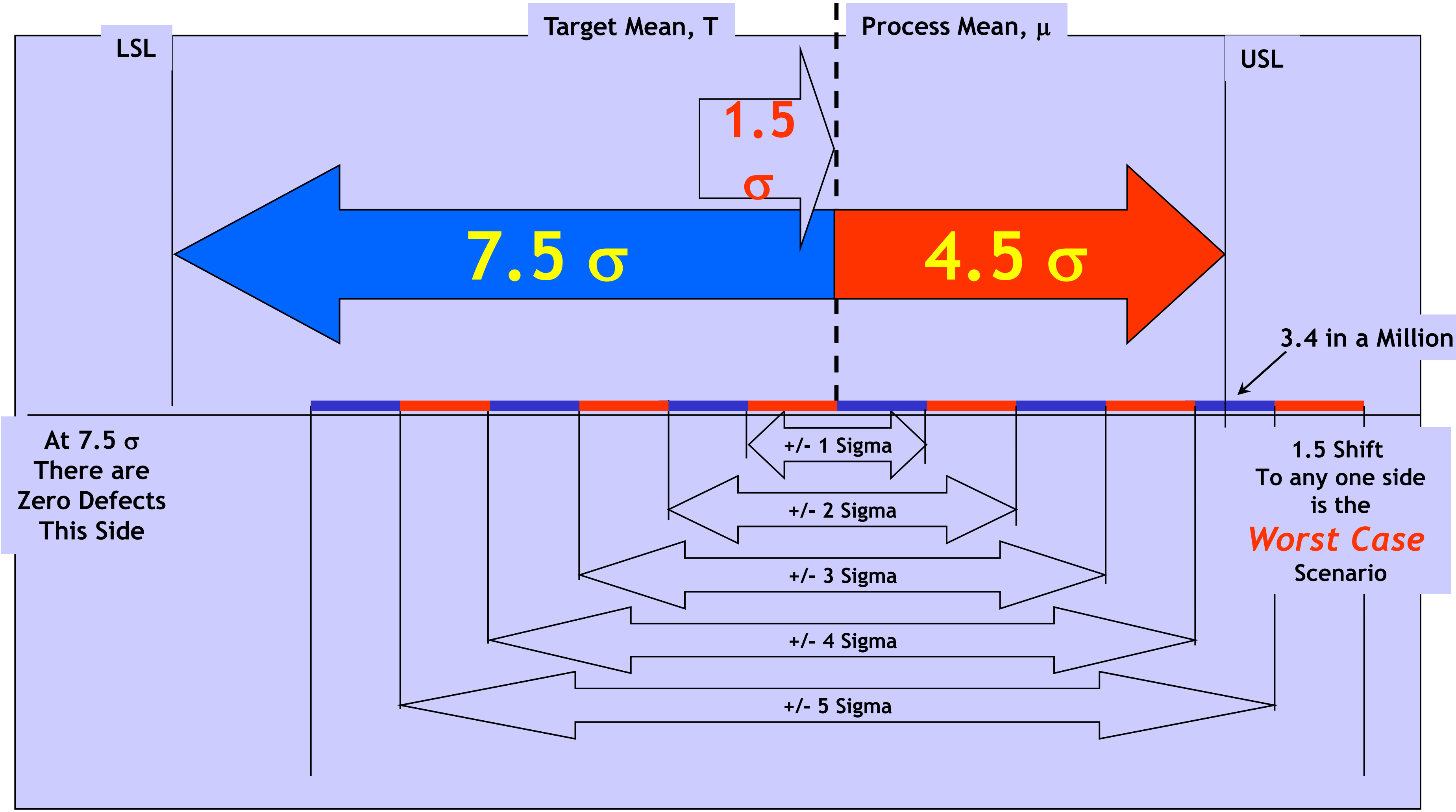
Higher Capability

In Long Term
Shift & Drift Causes
Std. Deviation To Go Up
And Hence:

Lower Capability

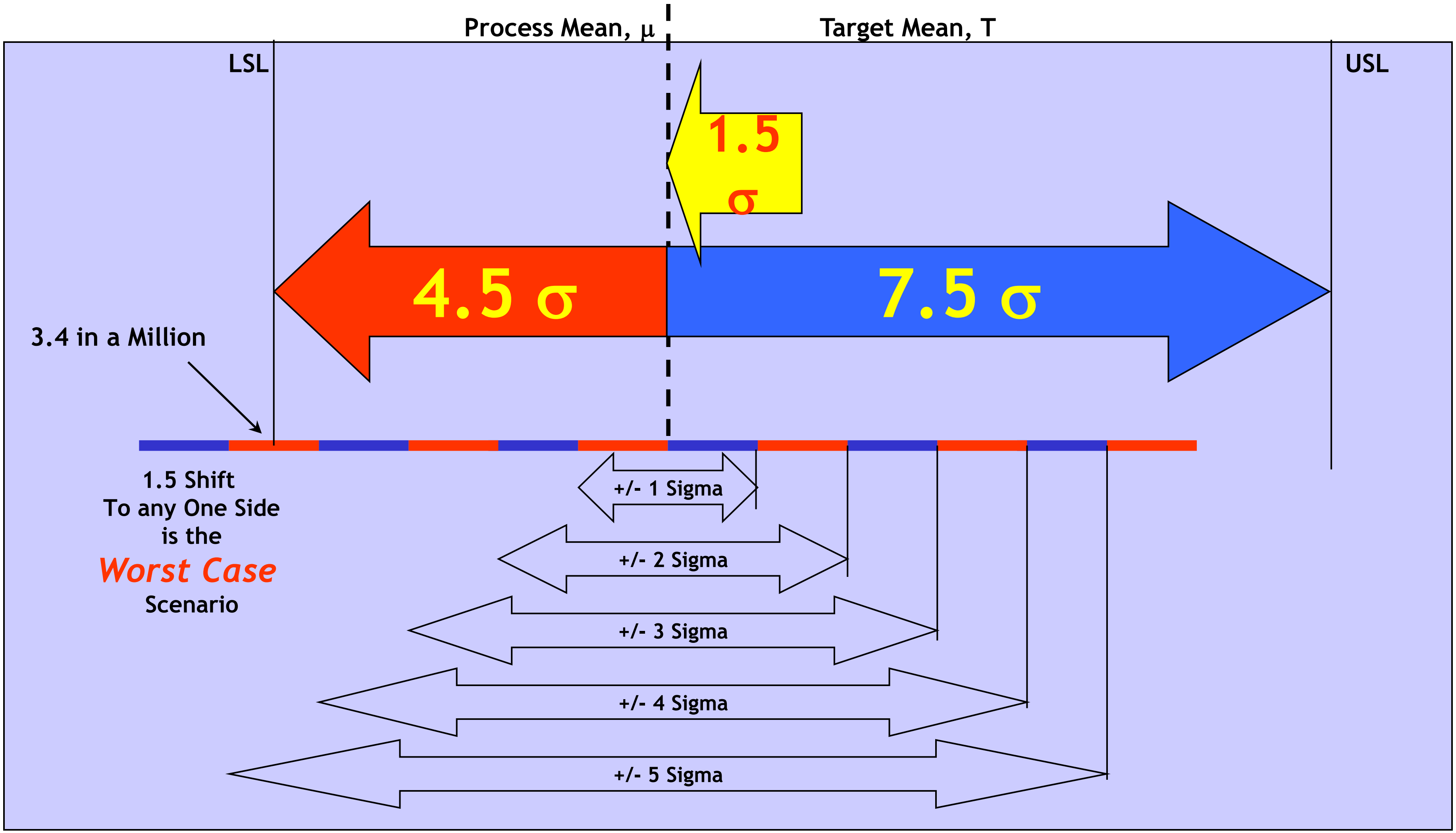
Six Sigma Concept (cont)

Six Sigma : Process Shifted towards Right, Post this we have 3.4 in Million



Six Sigma Concept (cont)

Six Sigma : Process Shifted Towards Left, Post this we have 3.4 in Million



What is a Six Sigma Process and where does the 1.5 Sigma Shift occur?

A popularly accepted definition of a six sigma process is one in which there are about 3.4 defects per million opportunities. i.e. Defects per million and the sigma level of a project can be used as project management statistics to evaluate the quality of a project.
The ideal goal for process capability is 3.4 defects per million which is almost negligible in number and considered a near-zero defect process. But, statistically a six sigma process means 2 defects per billion opportunities.

So, how did 2 per billion become 3.4 per million for a six sigma process? This is normally attributed to the 1.5 sigma shift

A layman's perspective on the 1.5 Sigma Shift

To understand the math behind the 1.5 sigma shift in project management statistics, consider a desired goal which has to be achieved within a particular environment and certain environmental conditions.

1) Any goal or result will have to be planned keeping 2 things in mind:
   a. The goal itself under standard environmental conditions
   b. Changing environmental conditions which may result in variation

However stable any process is, over an extended period of time, the environmental conditions change, which causes variation. Thus at the planning stage, these environmental changes need to be balanced by a compensation factor in order to account for these changes to ensure that the long term goal is met.
When expressed in an equation format, the following is obtained

"Short Term Goal = Long Term Goal + Appropriate Compensation Factor for Environmental Changes"

Keeping the above equation in mind, consider the following

In terms of statistics, 2 defects per billion opportunities in a project correspond to six sigma and 3.4 defects per million opportunities corresponds to 4.5 sigma.
The overall goal is a near-zero defect process, or a 4.5 Sigma Level for the process in the long term.
The environmental changes and the magnitude of this change is 1.5 Sigma *(Calculated empirically by Motorola as the Long Term Dynamic Mean Variation)*

Thus the Short Term Sigma Level (6) = Long Term Sigma Level (4.5) + Compensation Factor (1.5 Sigma Shift)
i.e. a Short Term goal of a 6 Sigma Level translates to 3.4 defects per million opportunities (4.5 Sigma Level) over the Long Term.

Short-term versus Long-term

DPMO Observed After Shift (In the Long Term)	Equivalent Sigma In Statistical Tables* Z_{LT}	Sigma Reported To the world Z_{ST}
308,770.2	0.5	2.0
158,686.9	1.0	2.5
66,810.6	1.5	3.0
22,750.3	2.0	3.5
6,209.7	2.5	4.0
1350.0	3.0	4.5
232.7	3.5	5.0
31.7	4.0	5.5
3.4	4.5	6.0

This is the long term capability or The worst case scenario for a given DPMO

This is the short term capability or The best case scenario possible for a given DPMO

$$Z_{ST} = Z_{LT} + 1.5$$

*One Sided Z Table

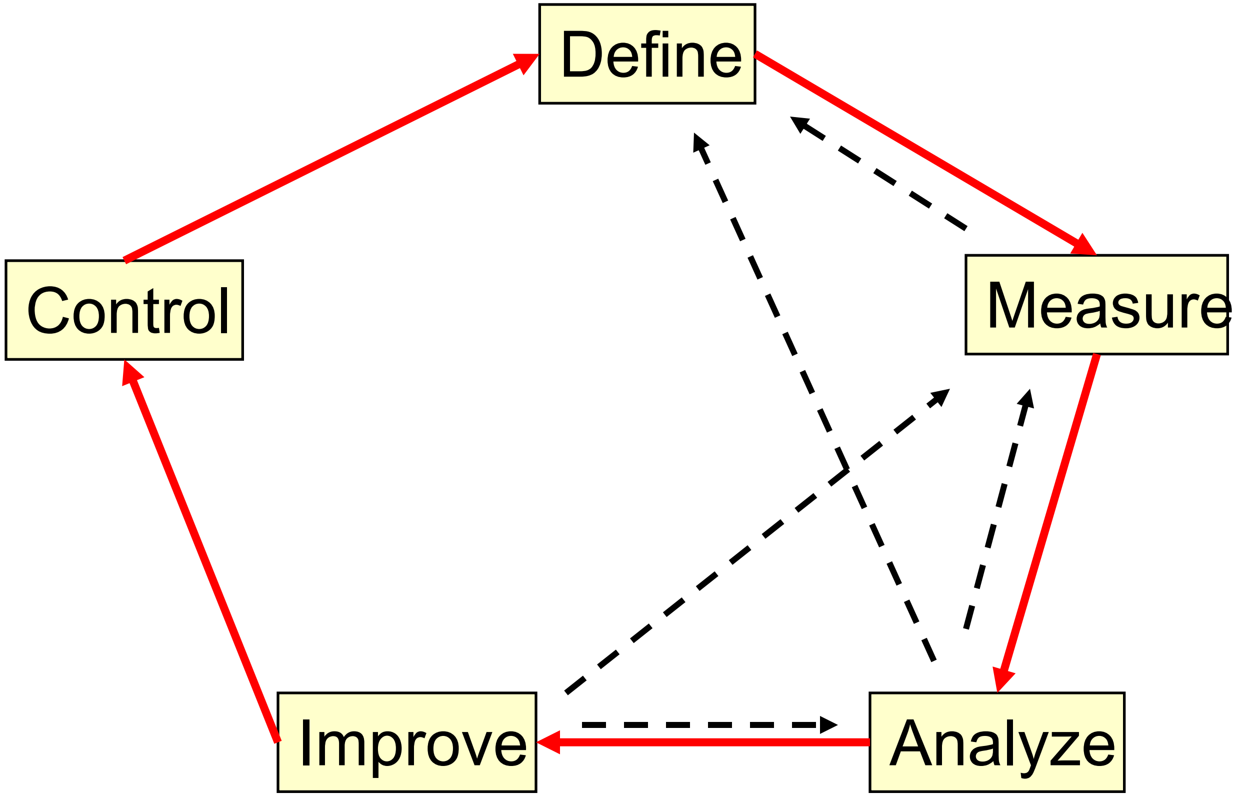
Caution! To Report Six Sigma, You must Observe:
3.4 Defects in a Million in Long Term Or
2 Defects in a Billion in Short Term
In Other words, if you get 3.4 DPMO in Short Term, You report 4.5
Since 3.4 Short-Term means 1350 DPMO in Long Term or 3.0 Sigma LT

Lean Six Sigma Green Belt

by
Rajiv Purkayastha
Six sigma MBB

D M A I C

Define Phase


Define
Measure
Analyze
Improve
Control

Define Phase Overview

What is the Define phase?

The Define phase is when your team identifies:

- Who your customers are and what their requirements are for your products and services
- The reason for doing the project and project boundaries
- The project team members and how they will work together
- What process you are trying to improve and what the process map looks like

Define Phase Overview

Why is the Define phase important?

This phase is important because it clearly and precisely describes the goals of the project, aligns the project with organizational priorities and lays the groundwork that will allow the team to remain focused.

Define Phase Overview

Steps involved in the Define phase:

Define 1: Identify Project CTQ's

Define 2: Develop Team Charter

Define 3: Define Process Map

Who is a Customer?

Anyone who receives or uses the service or the product we offer

"A customer is the most important visitor on our premises. He is not an interruption in our work. He is the purpose of it. We are not doing him a favor by serving him. He is doing us a favor by giving us the opportunity to do so".

Mahatma Gandhi quoted this in 1890,

Who is your customer?

- A customer is someone who
  - Uses your product or service
  - Decides to buy your product or service
  - Pays for your product or service
  - Gets impacted by your product or service
- Internal & External customers
- Primary & Secondary customer

Types of Customer?

Customer can be:

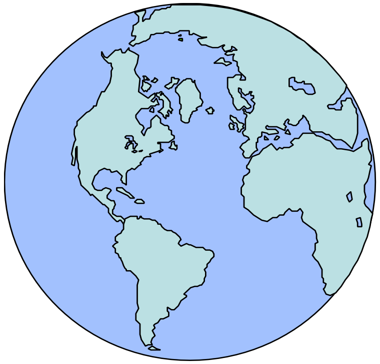
→Internal

→External

→Direct

→Indirect or Intermediate

Geographic Location?



Mercedes

Maruti 800

Even there can be various segments of customers

→Small/big (Business Volume)

Voice of Customer

- Six Sigma begins with the customer
- Customers find it easier to define what they <u>do not</u> want
- Customer CTQs are defined by customers
- Sources of customer CTQs
  - Survey results
  - Service reviews
  - Meetings

Examples of Voice of Customer

A Car Purchaser

- Good Acceleration
- Spacious
- Affordable
- Power Steering
- Loan Facility

A TV Purchaser

- Flat Screen
- Good Sound
- NTSC / PAL Compatible
- Affordable
- Good After Sales Service

A Caller to Help Desk

- Quick Answering
- Courteous Response
- Quick Problem Resolution

A Prospective Employee

- Good Salary
- Location Preference
- Flexible Working Hours
- ESOPs
- Separate Cabin

Example of an Air Conditioner

Customer voice

VOC Table

Sl. No.	Who is the customer?	What customer said (Voice of Customer)	What customer meant				
			What is the need?	When is the need felt?	Where is the need felt?	Why is the need felt?	How is the situation handled now?
1	Household member	AC should be silent	Sound sleep	At night	In the bedroom	To remain fresh next morning	Uses a ceiling fan that makes a lot of noise
		AC should be efficient	Good cooling	At night	In the bedroom	It gets very hot in May-June	Uses a ceiling fan that is not so effective in summer
		AC should not cost much	Affordability	N/A	N/A	Limited finance	N/A

Some Facts…….

Bad News

Out of 100 dissatisfied Customers

- ✓ Only 4 complain
- ✓ 96 don't complain and just go away

Out of 96 who go away

- ✓ Only 5 will eventually try your product/services
- ✓ 91 will never come back

Even More Bad News

Out of 100 dissatisfied Customers

- ✓ A typical dissatisfied customer will tell at least 10 more people about the bad experience. Only 4 complain
- ✓ 1 in 5 will tell 20 people.

Facts Cntd…….

Good News

✓95 out of 100 will do the business with you again if

❖Complaint is resolved accurately and quickly

The Paradox- Businesses spend six times more to attract new customers than they do to keep old ones

…….do we listen to our customer ?

Voice Of Customer (VOC)

The term Voice of the Customer (VOC) is used to describe customers' needs and their perceptions of your product or service.

VOC/ VOB data helps an organization to:

- ✓decide what products and services to offer.
- ✓identify critical features and specifications for those products and services.
- ✓decide where to focus improvement efforts.
- ✓get a baseline measure of customer satisfaction to measure improvement against.
- ✓identify key drivers of customer satisfaction.

Voice of Customer: Ways to capture

- Surveys
- Focus groups
- Interviews
- Word of Mouth
- Complaints … existing channels
- Intermediaries

Translate VOC to CTQ

- Illustration: Voice of the customer
  - "Today I phoned this airline.
  - I got through their number after several attempts.
  - Then I was put on hold.
  - Then I had to step through many option menus..
  - I could not find what I wanted in any of these options. Hence,
  - I was asked to wait for the „Next Available Operator".
  - The voice said „All our Customer Service Representatives are currently busy serving other customers like you". It kept repeating „Your call is important to us. Please be on the line. You will lose your position in the Queue if you hang up now"
  - I was desperate. I decided to hold on.
  - After many minutes of listening to boring music, I finally got through
  - But the Customer Service Representative told me , to meet them personally"
- Question: What is the VOC in the above situation?

Translate VOC to CTQ

- Want/Need:
  - VOC: I want simple & quick service,
    - I want easy menu systems
    - I want the service, I am seeking to be one of the options
    - I want an operator to talk to me as soon as possible
    - I want the solution available to my kind of challenge.
  - VOC mapped to Service/Product Requirement:
    - Ease of use, *as seen by the customers*
    - End to End Cycle Time, *as seen by the customers*
    - Ability to Provide Service *that the customers want*
  - VOC translated to Measurements:
    - # of minutes taken to reach an operator
    - # of minutes taken to complete the service
    - Whether or not the service requested was provided
    - Customer‟s rating on 1-5 point scale in a survey
    - on various parameters such as „Ease of Use‟, „Prompt Service‟.

Translate VOC to CTQ

- CTQ:
  - <u>#minutes taken to reach an operator:</u>
    - **Average Time, Maximum Time, Median Time etc.**
    - **or % of calls which exceeded a particular time limit**
      - *not to exceed a Maximum limit set (Quality Goal)*
  - <u>#minutes taken to complete the service:</u>
    - Average Time, Maximum Time,
    - or % of calls which exceeded a particular time limit
      - *not to exceed a Maximum limit set (Quality Goal)*
  - <u>%times the service requested was provided:</u>
    - *not to fall below a Minimum limit set (Quality Goal)*
  - <u>% of Customers rating **5** on 1-5 point scale in a survey:</u>
    - <u>on various parameters such as „Ease of Use", „Prompt Service"</u>
      - *not to fall below Minimum limit set (Quality Goal)*

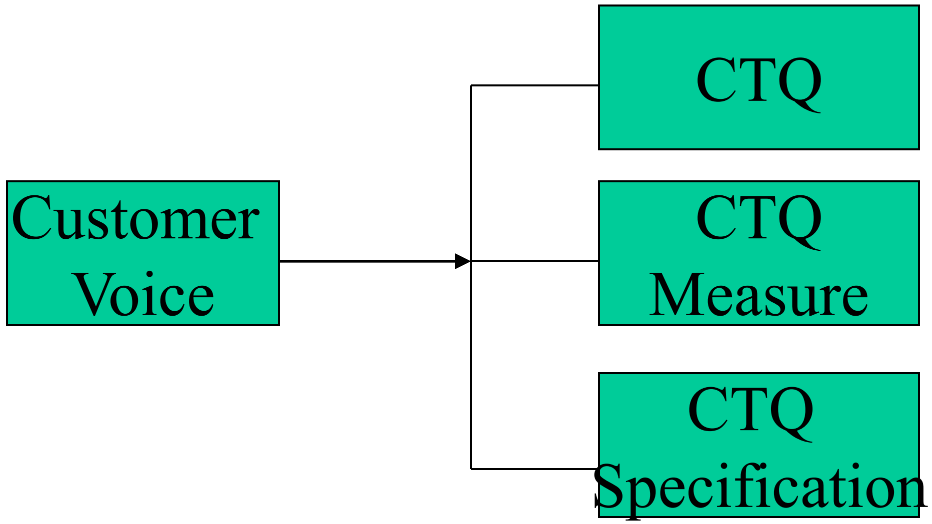
CTQ (CRITICAL TO QUALITY)

A CTQ is a Product or Service Characteristic that satisfies a Customer Requirement or Process Requirement

CTQ Types

- **Business CTQ**
  - **Profitability, C Sat, E Sat……….**
- **Customer CTQ**
  - **On-time Delivery, Defect Levels……….**
- **Unit CTQ**
  - **Profitability, Seat Utilization……………….**
- **Project CTQ**
  - **Errors/LOC, Schedule Variance %….**

Cont….



Examples

Customer Voice : Steel sheet thickness is not uniform
CTQ : Sheet thickness
CTQ Measure : Thickness in mm
CTQ Specification : Specified thickness

Example

Lets take an Example of a Coffee Shop

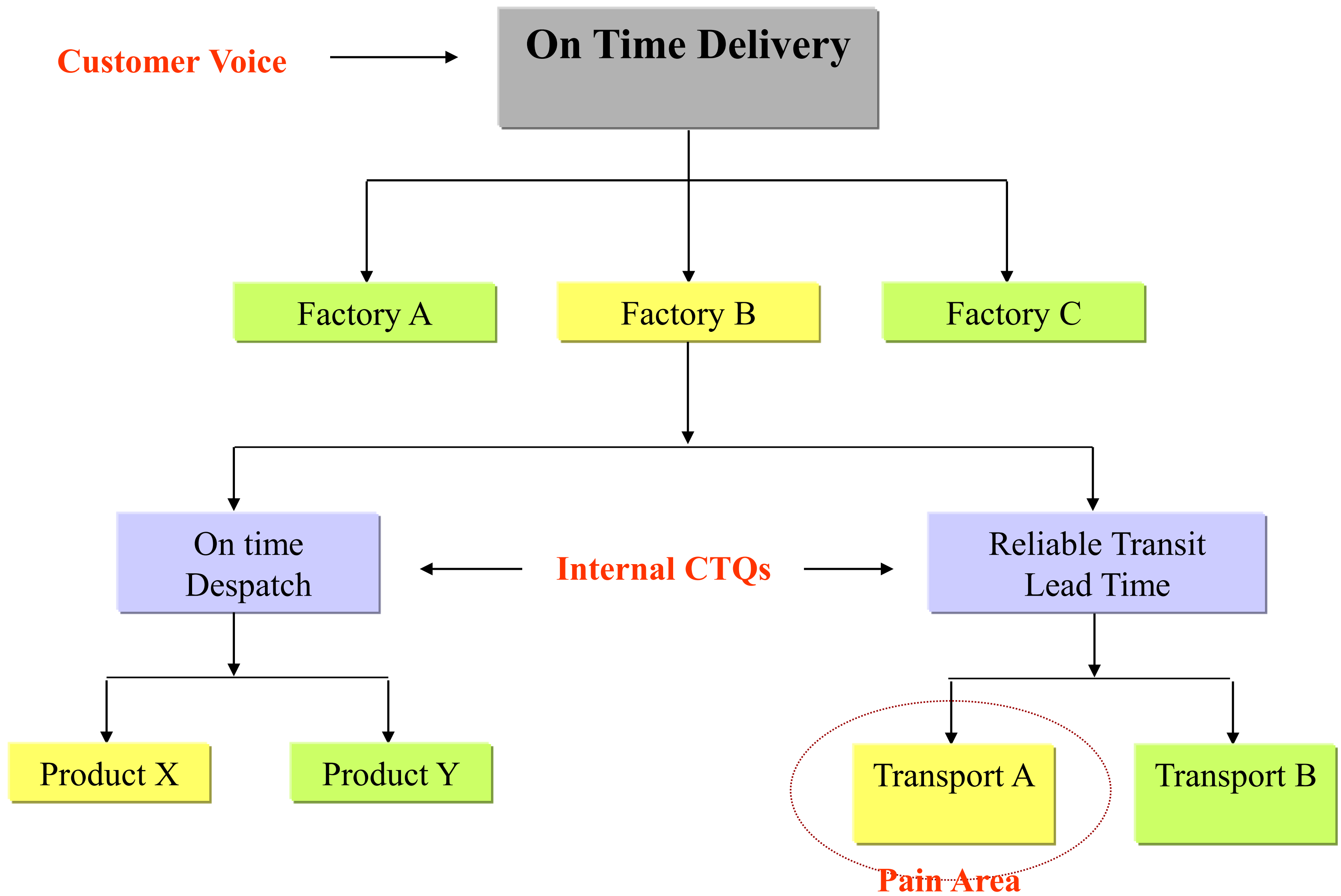
Tools to analyze VOC and to define CTQ

- Case 1: Too many Requirements - Use Affinity Diagram
  - Affinity diagram, as the name suggests organizes large amount of qualitative inputs into more meaningful categories.
  - How do we make an affinity diagram?
    - Groups Ideas / data that seem to belong together
    - Let it emerge and not have predefined groups already
    - Clarify ideas/data if need be
    - See if smaller sets belong to a larger group
    - Build consensus
    - Name the group finally
- Case 2: Prioritizing Requirements – Use Kano Model
  - Kano Model can help in prioritizing requirements as
    - Must Be
    - One Dimensional
    - Delighter
- Case 3: Translating customer needs to quantitative requirements – Use CTQ Tree

Why Create CTQ Tree

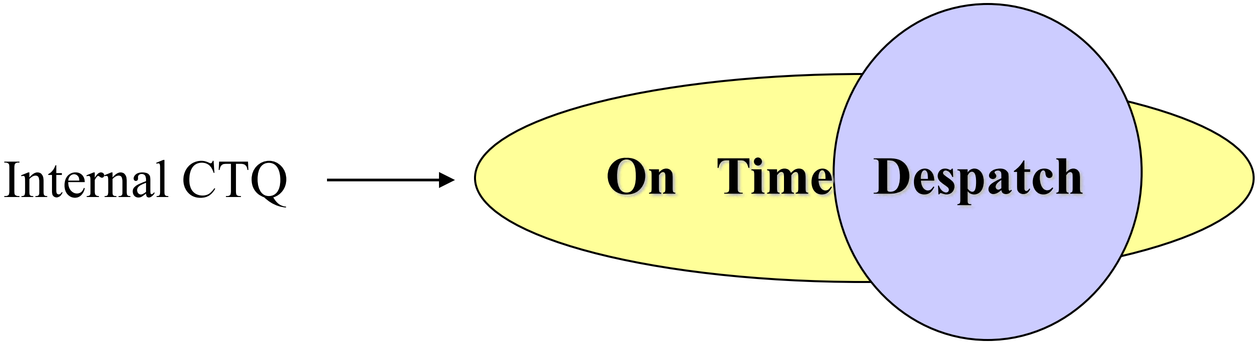
- Translates broad customer requirements into specific critical to quality (CTQ) requirements
- Helps team to move from high level to detailed specifications
- Ensures that all aspects of need are identified

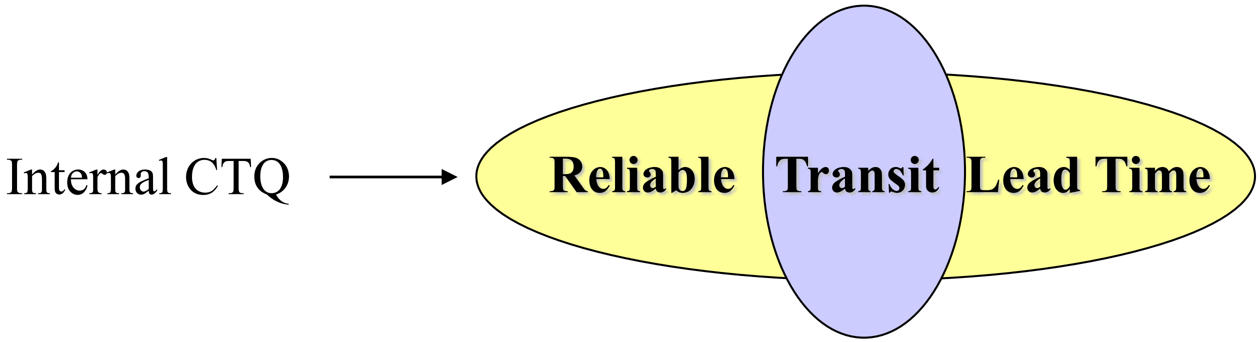
CTQ Drill-down



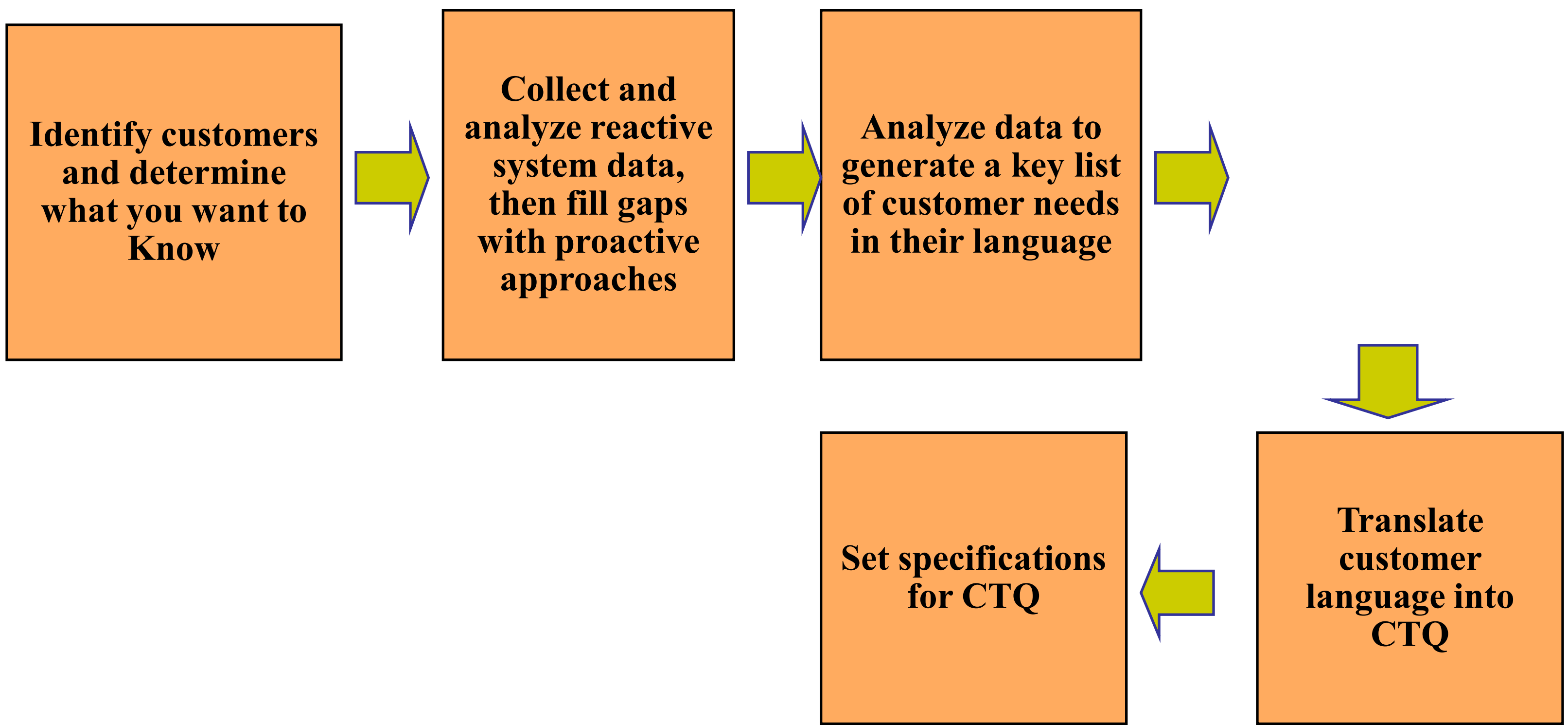
CTQ Drill-down

- „On Time Delivery" is a Customer Voice
- There are 2 internal CTQs for „On Time Delivery"
- All internal CTQs may not be attached to a CBP



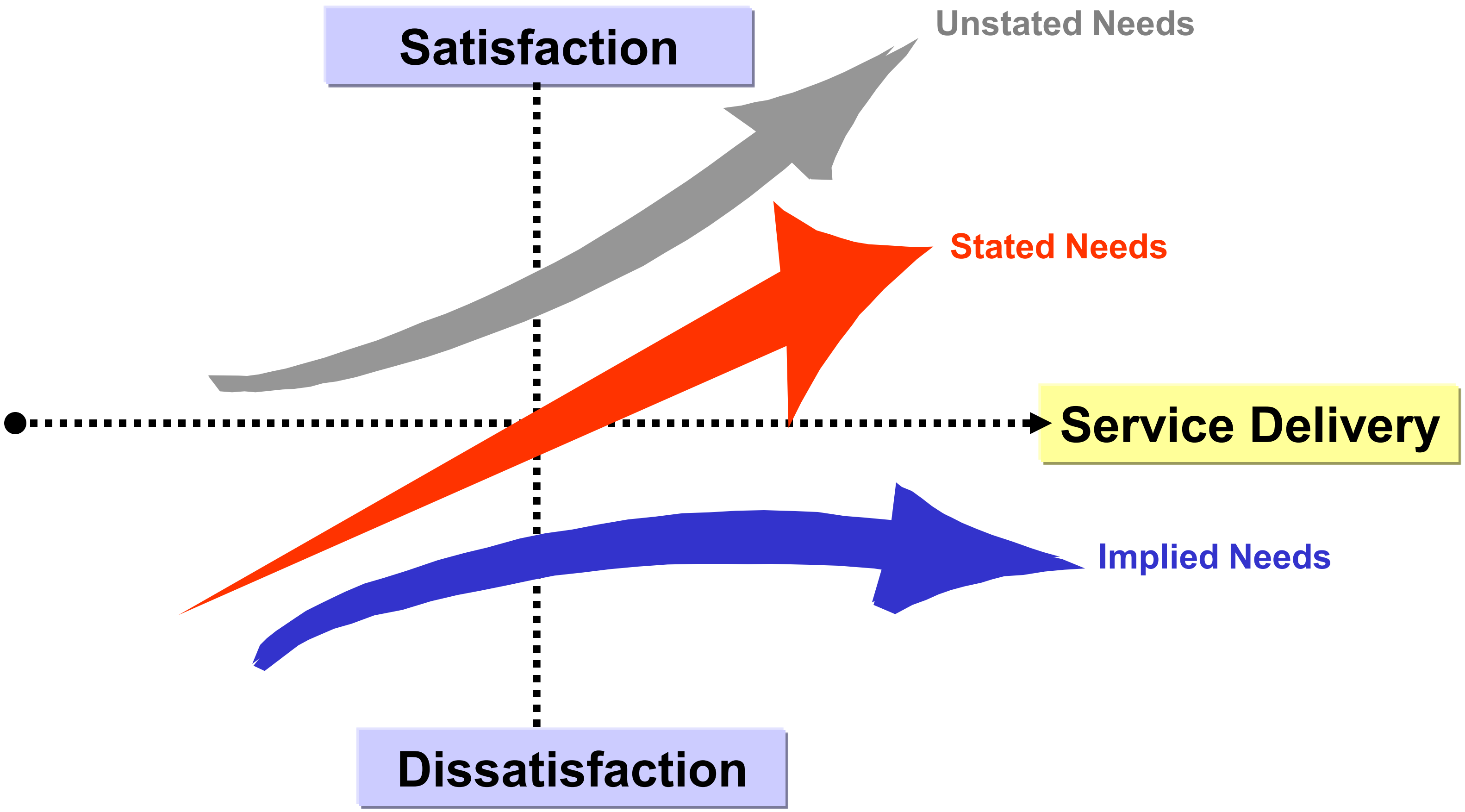


Process for VOC to CTQ



Kano Diagram

- Kano analysis classifies customer CTQs into three categories based upon the impact of the need on his satisfaction



Implied Needs

- Taken for Granted by Customer

- Lack of Delivery causes high Dissatisfaction

- Delivery does not cause Satisfaction

- Noticed only by its absence

- A Dissatisfier

Example-

1. Basic need for a hospital is to have qualified doctors & standard equipment.

2. At any restaurant, if we order sweet tea, and they bring it, they don‟t get any credit for it; if they bring unsweetened tea, we‟re unhappy.

Stated Needs

- Demanded by Customer
- Delivery causes Satisfaction
- Lack of delivery causes Dissatisfaction

Example –

1. More mileage performance in a car
2. Less waiting time in airport.

Unstated Needs

- Not usually thought of by Customer
- Delivery causes high Satisfaction
- Lack of delivery does not cause dissatisfaction
- Noticed only by its presence / delivery
- A Satisfier

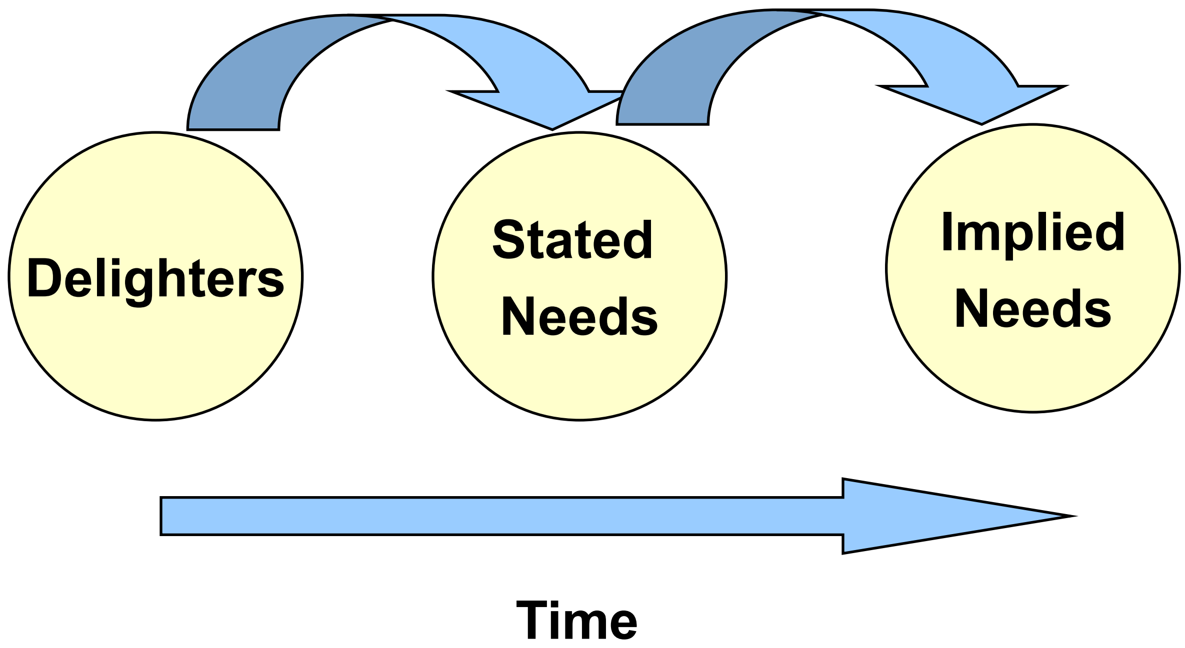
Example –

Internet access on a plane is not expected so will not upset if not present but will delight if it is.

Shifting Needs

•Over a period of time, Delighters become Stated Needs

•Over a period of time, Stated Needs become Implied Need



VOC EXAMPLE

VOC/VOB	CTQ	Defect Definition	Measure	Kano Status
"Your cars take too damn long to start."	Engine starts fast	Engine start time is greater than 3 seconds	Time from turning of key to sustained idle (in seconds)	Must be
"Do you have more than one person answering the phones there?"	Call answered promptly	Any call answered after third ring	Time from beginning of first ring to greeting.	Less the better

Project Charter

A project charter is a written document that provides purpose, goals and direction for the project team.

Project Charter :

- Clarifies what is expected of the team
- Keeps the team focused
- Keeps the team aligned with organizational priorities
- Transfers the project from the champion to the improvement team

D M A I C

Business Case

Scope

In Scope

1)..
2) ....

Out of Scope

1) ....
2) ....

Problem Statement

Definition of a Defect

Goal Statement

CTQs

1) .... 2) .... 3) .... 4) ....

Process Measurement

	Current	Target
Benchmark		
% Yield		
Sigma Level		

Benefits

Projected Savings from the Project:
Process Improvement:

Milestones

	15th Aug		1st Sept		15th Sept		15th Oct		30th Oct	
Define										
Measure										
Analyze										
Improve										
Control										

Roles

Sponsor	
Champion	
Master Black Belt	
DGM	
Black Belt	
Green Belt	
Team Members	

Big Y Alignment

Stakeholder	Big Y	Alignment	Stakeholder	Big Y	Alignment
Customer	Customer Satisfaction	☐	Management	Digitization / Automation	☐
Employee	Employee Satisfaction	☐	Customer	Network Quality Improvement	☐
Management	Process Institutionalization	☐	Management	Productivity Improvement	☐
Shareholder	OPEX / CAPEX Optimization	☐	Shareholder	Revenue Enhancement	☐

Elements of Project Charter

Project Charter Elements

- **Business Case**
- **Problem and Goal Statement**
- **Prepare Scope**
- **Milestones**
- **Roles**

The Business Case (Why Project)

- Why is the project worth doing?
- Why is it important to do it now?
- What are the consequences of NOT doing the project?
- What activities have higher or equal priority?
- How does it fit with the business initiatives and target?
- Examine and include assessment of intellectual property

Problem Statement

The Problem Statement is an objective description of the "pain" experienced by internal and/or external customers. Problem Statement must tell us:

- What is wrong or not meeting our customer‟s needs?
- When and where do the problems occur?
- How big is the problem?
- What is the impact of the problem?

Poor Example:

Our customers are angry with us and late in paying their bills.

Improved Example:

In the last 6 months, 20% of our repeat customers are over 60 days late paying our invoices. The current rate of late payments is up from 10% in 1990 and represents 30% of our outstanding receivables This negatively affects our operating cash flow

Examples

Incorrect

Projects are delayed because we do not have a good project management system

Correct

4 Projects out of 10 completed between Jan to Dec’ 2016 were delayed beyond the scheduled completion date resulting in a annualised COPQ of USD 1 million.

The Goal Statement

- Definition of the improvement, team is seeking to accomplish?
- Starts with a verb (reduce, eliminate, control, increase)
- Tends to start broadly–eventually should include a measurable target and completion date
- Must not assign blame, presume cause, or prescribe a solution!

Examples

Incorrect

Install a new testing methodology for reducing customer end rejections

Correct

Reduce customer end rejections by 50% by August 2017.

Project Scope

- Purpose
  - The Project scope defines the boundaries of the business opportunity.
- Project Scope
  - What are the boundaries,the starting and ending steps of a process.of the initiatives?
  - What parts of the business are included ?
  - What parts of the business are not included ?
  - What ,if anything,is outside the team's boundaries?

Longitudinal Scoping

- Longitudinal scoping is done on the length of the process
  - e.g. – From the receipt of PO till the delivery at the distributor's go-down
  - e.g. – From the time of customer reporting the complaint till final satisfaction confirmation

Lateral Scoping

- Lateral scoping is done on the breadth of the process
  - e.g. – All despatches from North & South regions
  - e.g. – Calls received during general shift

Project Charter

Business Case

End to End Provisioning process begins from the date of purchase order raised by the customer to the implementation of link. This involves the series of activities performed by Sales, Revenue Assurance, Network Planning, O&M, NOC Provisioning & Testing. This integration of work shows the performance of whole organization to the customer and any delay in this end to end activity results in the customer dissatisfaction as well as revenue loss.

Problem Statement

High Lead time for End to End Provisioning Process.

On the base of data for Sept'05 the lead time of end to end provisioning is 31 days with defect level (>15days) is 67%.

Goal Statement

Reduction in Lead time for end to end provisioning to 15 days with defect level (>15 days) to 25%

	Current	Target
Average P.O. to Implementation	**31 days**	**15 days**
Defect Level% (>15days)	**67**	**25**
Sigma Level	1.06	**2.17**

Milestones

	1st Sep		15th Oct		15th Nov		30st Dec		15th Mar	
Define	■	■								
Measure		■	■	■						
Analyze			■	■	■	■				
Improve		■	■	■	■	■	■	■		
Control								■	■	■

Scope

In Scope

1) End to End Provisioning orders of Clear Channel data customers
2) Orders which do not require fiber extension

Out of Scope

1) End to End Provisioning orders of voice customers.
2) Orders require fiber extension.

Definition of a Defect

Any case where lead time for order provisioning from P.O. date to Link Handover is greater than 15 days.

CTQs

↓1) Average Lead time of Order Provisioning

↓ 2) Defect Level for Order Provisioning (> 15 days)

Benefits

Enhanced Customer Satisfaction

Revenue Enhancement

Roles

Sponsor	N Arjun
Champion	Ramamurthy Kolluri
Master Black Belt	Arun Malik
Black Belt	Rajiv Purkayastha
Team Members	KV, JJ, JM, KR, RS,RG, MKB,MG

Big Y Alignment

Stakeholder	Big Y	Alignment	Stakeholder	Big Y	Alignment
Customer	Customer Satisfaction		Management	Digitization / Automation	
Employee	Employee Satisfaction		Customer	Network Quality Improvement	
Management	Process Institutionalization		Management	Productivity Improvement	
Shareholder	OPEX / CAPEX Optimization		Shareholder	Revenue Enhancement	

Develop Team Charter

Business Case

High level brief of process / project

WHY is it IMPORTANT to do this project?

Why is it important to do this project NOW?

What would happen if this project is not done?

What will be the impact of this project in case of a successful closure?

Problem Statement

WHAT is the problem?

How big is the problem? (use real data or leave blanks to fill in when you get the data

When was the problem evident? (dates that the data represents or was collected)>

What is the impact of the problem (time, $, customer satisfaction, etc.)

Goal Statement

The Goal statement should be S*M*A*R*T*

(" Specific, Measurable, Attainable, Relevant, Time bound)

Always start with a verb.."Increase, Reduce, Improve"

Start and Stop Points

Project boundaries

Scope

What processes, systems, products, services, channels, etc. will you consider / exclude in this project?

In Scope

Out Scope

Defect

Goal

Opportunity

Unit

DPMO

Sigma

Team Activity…15 minutes

Develop a Team Charter for the following scenarios. Leave blanks where you do not have numbers available

•Case A: Current AHT for the process is 22 as against a target of 18

•Case B: Cycle Time of the Full and Final Settlement is 30 days as against the industry average of 14 days

•Case C: The CSat scores for the process are at 50% as against a target of 70%

•Case D: The current Attrition percentage for Daksh is at 6% (monthly) as against the industry average of 4%

Scoping Techniques

- Write inside the box what you think project covers
- Write outside the box what you think project excludes

Example for an „On time Despatch" project

- Longitudinal
  - Starts after receipt of PO from customer
  - Ends at the despatch from factory
- Lateral
  - Despatches from Mumbai plant
  - All despatches during shift A
  - Despatch through transporter X

- Any IT related work
- Any transit delays
- Product damages
- Billing errors
- Non-availability of customer

Project boundary

Project milestones

- **Should be preliminary, high-level project plan with dates**
- **Should be tied to phases of DMAIC process**
- **Should be aggressive (Don’t miss the “window of opportunity.”)**
- **Should be realistic (Don’t force yourselves into corrective rather than preventative solutions.)**
- **Revisit and update initial plan – as appropriate**

Project Plan

- Purpose
  To document the major milestones and timing.
- Project Plan

	Jun'16				Jul'16				Aug'16				Sep'16				Oct'16			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W!	W2	W3	W4	W!	W2	W3	W4
Define																				
Measure																				
Analysis																				
Improve																				
Control																				

Team Roles

People, expectations, responsibilities

- **Who is the project sponsor (Unit Champion?)**
- **Clearly define the roles in the team (owner, members, etc)**
- **Is the team's role to implement or recommend?**
- **What authority does the team have to act independently?**
- **What is the role of the team leader (Black/Green Belt) and the team coach (Master Black Belt)?**
- **Are the right members on the team? Functionally? Hierarchically?**

Team

Sponsor

Champion

Black Belt

Green Belt

Yellow Belt

Members

Teaming Roles

- Champion
  - Is the Head of the Business Unit / Division / Location / Function
  - Decides on the Green Belt for the project along with the Black Belt
  - Must ensure that the Green Belt has the project deliverable in his objectives
  - Reviews projects periodically
  - Adds value in project reviews since he is hands-on in the business
  - Clears road blocks for the team
  - Has the overall responsibility for the project closure

Teaming Roles

- Black Belt
  - Trains others in Six Sigma methodologies & concepts
  - Conducts programs on Statistical tools
  - Sits along with the Business Unit Head and helps project selection
  - Provides Application Assistance by facilitating team discussions
  - Helps review projects with Business Unit Head
  - Informs Business Unit Head of project status for corrective action

Teaming Roles

- Green Belt
  - Is the Team Leader for a Project
  - Selects other members of his project team
  - Defines the goal of project with Champion & team members
  - Defines the roles and responsibilities for each team member
  - Identifies training requirements for team along with Black Belt
  - Helps make the Financial Score Card along with his CFO

Teaming Roles

- Yellow Belt
  - A Team Member is called as Yellow Belt
  - Team Members help design the new process
  - Team Members drive the project to completion
- Guidelines for team members
  - Up to 2 people per project
  - People who have stake in the process
  - People who are benefited by removal of pain area
  - People who have complementary skills

ARMI Model

		ARMI MODEL				
Key Stakeholders	Role	Define	Measure	Analyze	Improve	Control
Mohammed Al Zaro	Sponsor	A	I	I	I	A
Rajiv Purkayastha	MBB	M	M	M	M	M
Publilius Syrus	Finance Contoller	M	M	M	M	M
Haider Ali	HR Leader	M	M	M	M	M
Ahmed M Habib	Team Member	M	M	M	M	M
Adel Ghafan Saeed	Team Member	M	M	M	M	M
Sushanta Singha	Team Member	M	M	M	M	M
Sourabh	Team Member	M	M	M	M	M
Vinod shankar	Team Member	M	M	M	M	M
Sanjeev gupta	Team Member	M	M	M	M	M

Characteristics of a Good Team

ROLES

Do
all members
know what is
expected of them?

NORMS

What are some of
the ground rules
that the team follows?

GOALS

Are the goals
clearly stated, accepted
and agreed upon by
all team members?

RELATIONSHIPS

Is the team continuously
working to build
and maintain rapport
between its members?

GRPI Model

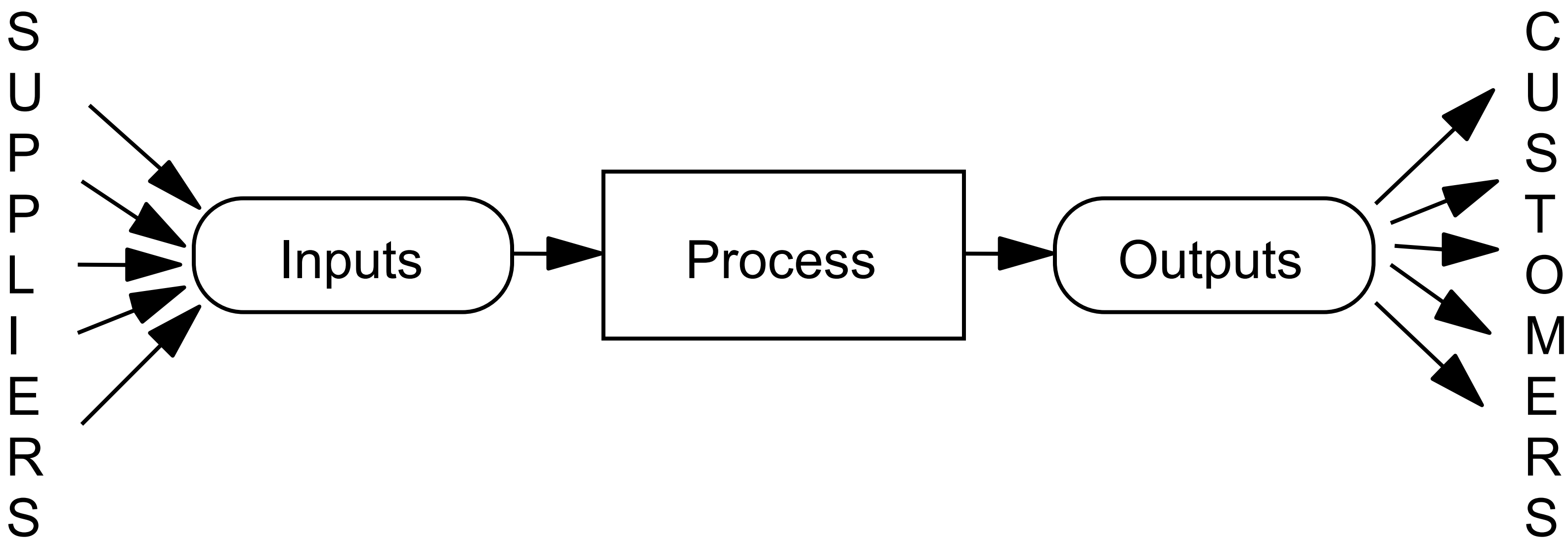
Team Members	Goals	Roles	Processes	Interpersonal	Average
Abdur Rahim	100	100	80	100	
Yousuf Ali Behzad	80	80	100	90	
Tom Akers	100	90	100	100	
Reem Ghassan	90	80	100	90	
Mohd F. Alhmdan	90	90	100	100	
Sourabh	80	80	90	100	
Vinod Shankar					
Masood Ali	90	80	100	100	

PROCESSES

- **All activity takes place in terms of a process.**
- **Shocking lessons**
  - #1: Most people do not think in terms of processes. They would rather think in terms of isolated events.

  - #2: When convinced of the value of thinking in terms of processes, most people still don"t think in terms of processes.
  - #3:The word "process" generates fear and resistance.

WORK AS A PROCESS

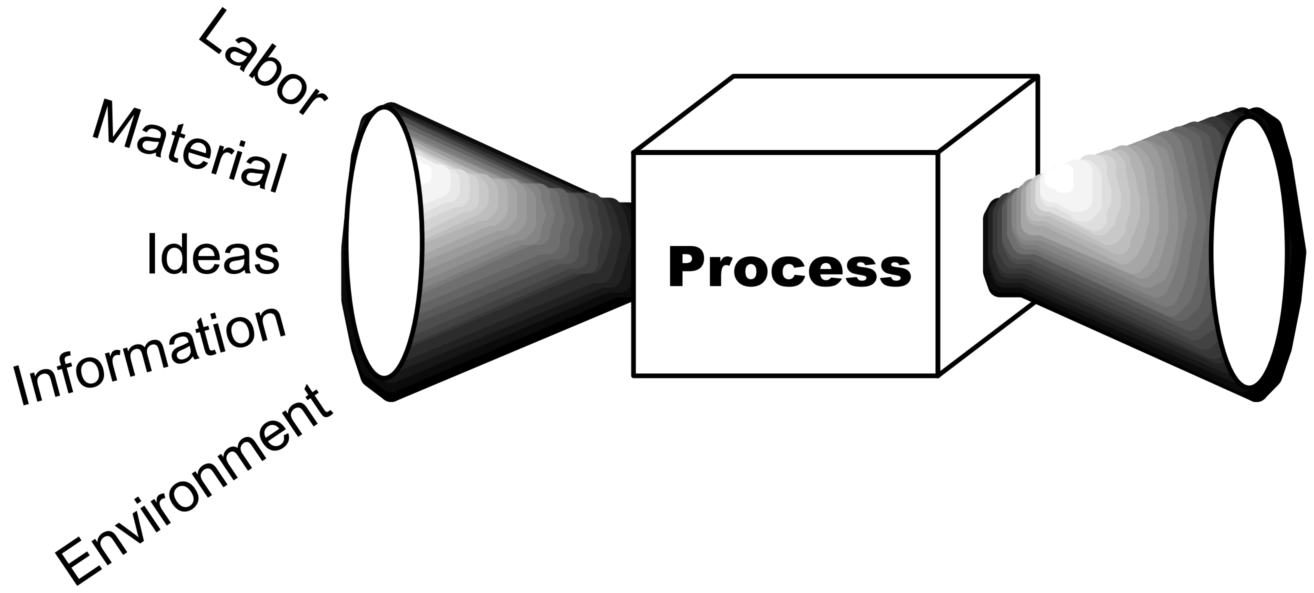


- Applies to all kinds of work, whether repetitive in nature or "one-of-a-kind."
- Having a high-level view of a process helps to:
  - define project boundaries (starting and ending points);
  - describe where to collect data.

WHY CREATE A SIPOC MAP?

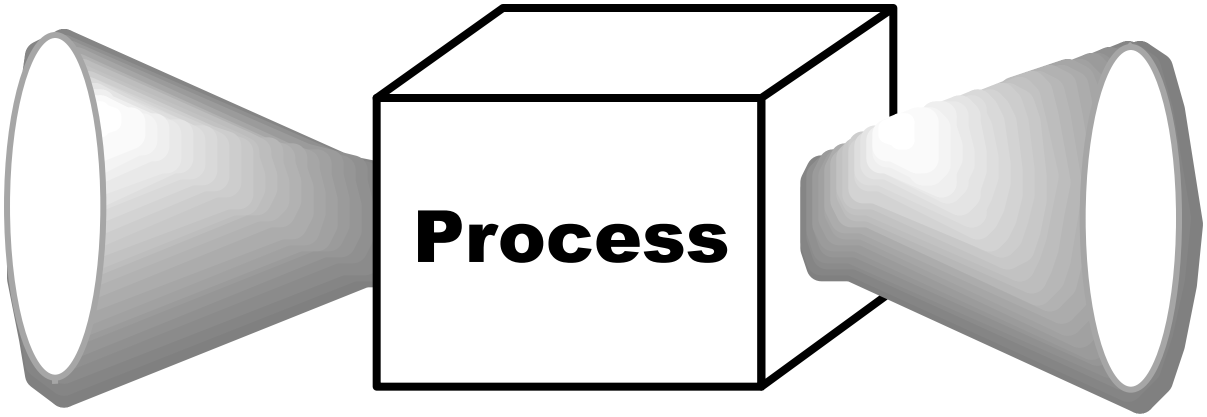
- **To develop a high-level view of the process.**
- **To avoid “scope creep.”**
- **To highlight areas for improvement.**
- **To ensure focus on the customer.**

SIPOC: INPUTS

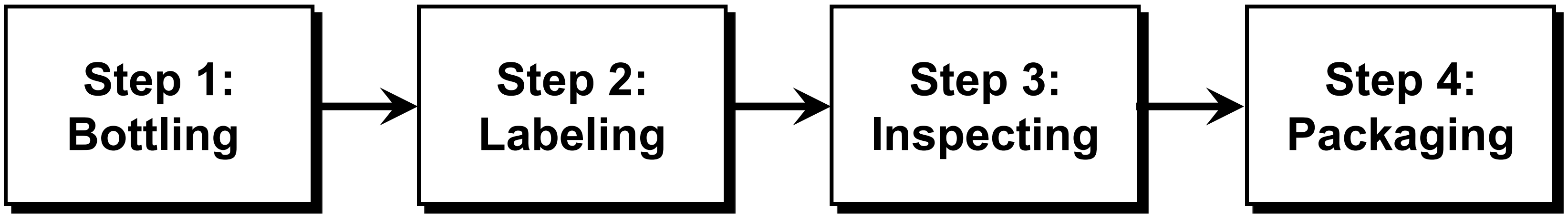


- **You may end up with 50–100 input variables at this point.**
- **We will continue to focus on using funneling tools throughout the DMAI²C process.**

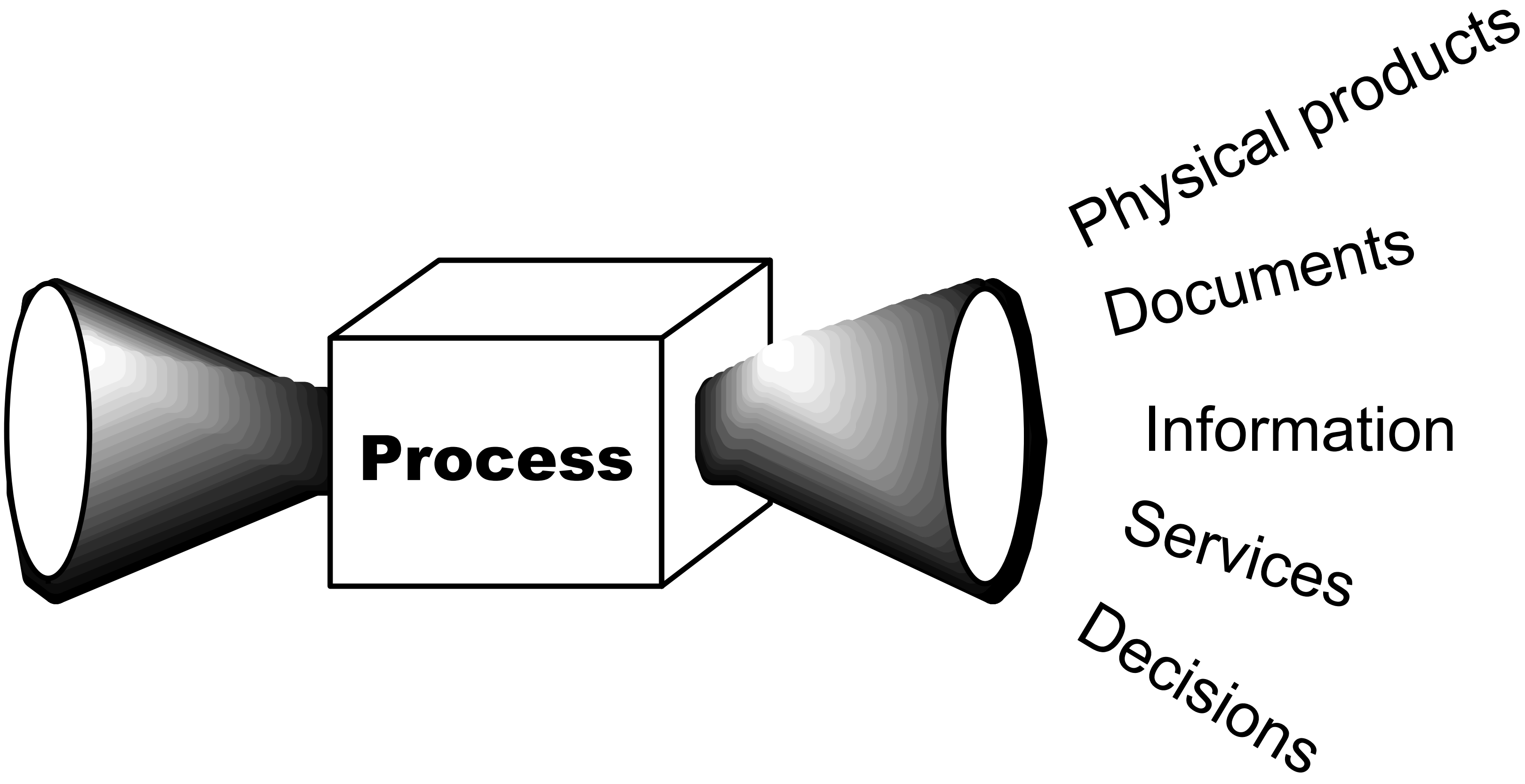
SIPOC: HIGH-LEVEL PROCESS VIEW



– A high-level view is often captured as a **top-level flowchart**



SIPOC: OUTPUTS



QUESTIONS TO HELP WITH SIPOC

- **Purpose**
  - Why does this process exist?
  - What is the purpose of this process?
  - What is the outcome?
- **Outputs**
  - What product does this process make?
  - What are the outputs of this process?
  - At what point does this process end?
- **Customers**
  - Who uses the products from this process?
  - Who are the customers of this process?
- Inputs/Suppliers
  - Where does the information or material you work on come from? Who are your suppliers?
  - What do they supply?
  - Where do they affect the process flow?
  - What effect do they have on the process and on the outcome?
- Process steps
  - What happens to each input?
  - What conversion activities take place?

SIPOC EXAMPLE

Suppliers	Inputs	Process	Outputs	Customers
Manufacturer	Copier		Copies	You
Office Supply Company	Paper	Making a photocopy		File
	Toner			Others
Yourself	Original			
Power Company	Electricity			

Process Steps

Put original on glass → Close Lid → Adjust Settings → Press START → Remove originals and copies

SIPOC – Example

S	I	P	O	C
Suppliers	**Inputs**	**Process**	**Outputs**	**Customers**
End Customer	Signed copy of the Purchase order from customer Procedure for order booking process	C  P **Customer order booking**	Sale order number Order Indent Full Cost Model Order backlog projection	Project Manager and Project execution team

Major process steps

Start → Create sale order/ Project definition in SAP → Create order indent & Full Cost Model (FCM) → Carry-out costing Of Each line item in the Sale order → Seek FCM approval → Transfer the Order with all documents to execution team → End

HOW TO CREATE A SIPOC MAP

- **Name the process.**
- **Clarify the start and the stop (boundaries) of the process.**
- **List key outputs and customers.**
- **List key inputs and suppliers.**
- **Identify, name, and order the major process steps.**

Quality Function Deployment (QFD) or House of Quality

Definition of QFD

- Quality Function Deployment (QFD) is a process used to determine product development characteristics that combine technical requirements with customer preferences

- Structured methodology to identify and translate customer needs and wants into technical requirements and measurable features and characteristics:

  - From marketing and sales
  - To research and product development
  - To engineering and manufacturing
  - To distribution and services

- Used to identify Critical to Quality Characteristics (CTQ's)

- Yoji Akao is widely regarded as the father of QFD

Definition of QFD

Structured methodology to identify and translate customer needs and wants into measurable features and characteristics of a product or service

"Quality function deployment is a visual, connective process that helps teams focus on the needs of customers throughout total development"

Clausing, 1990

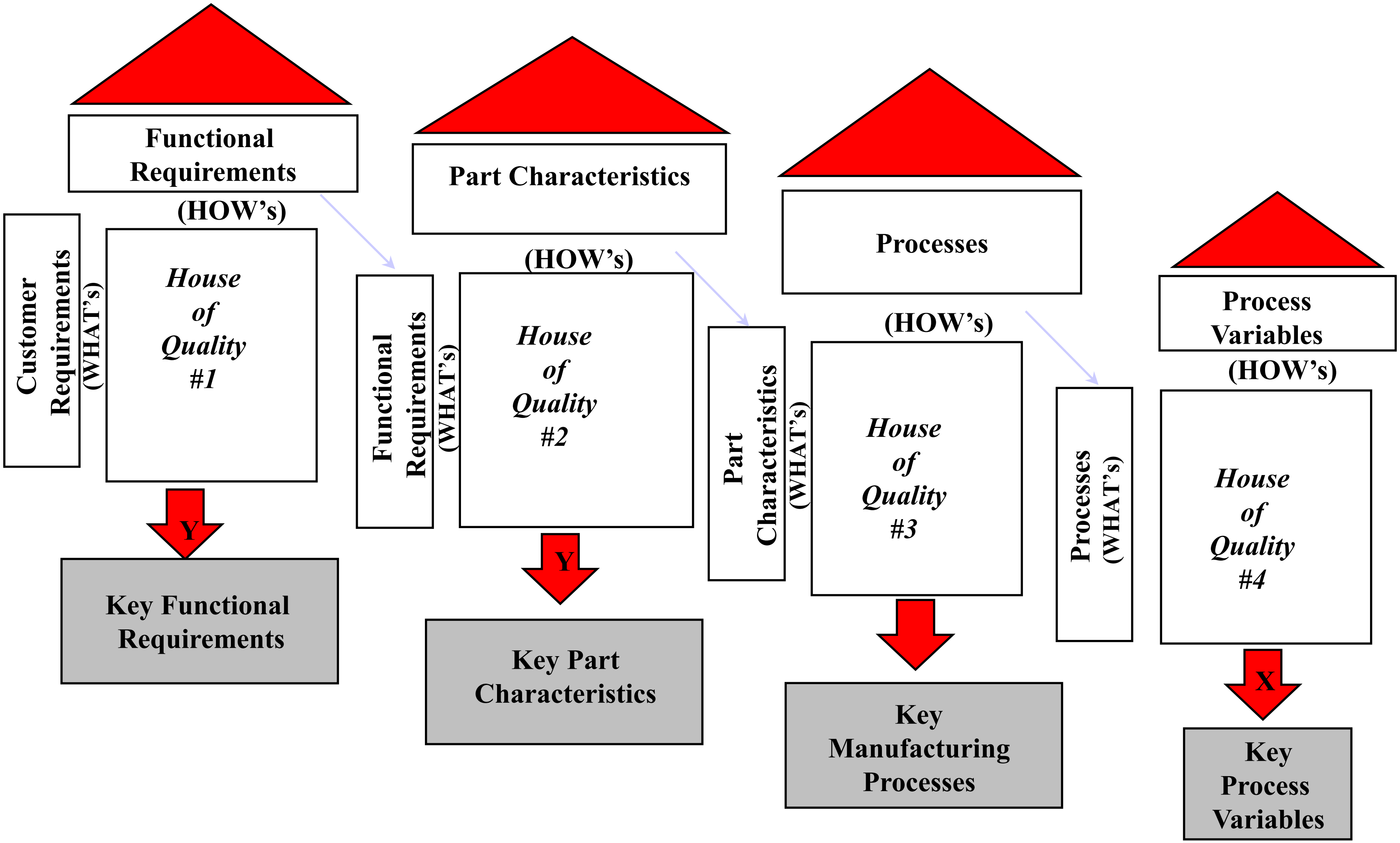
QFD FLOWDOWN

Manufacturing Environment	Software Environment	Service Environment
Customer Wants	Customer Wants	Customer Wants
↓	↓	↓
Technical Requirements	Product Functionality	Service Requirements
↓	↓	↓
Part Characteristics	System Characteristics	Service Processes
↓	↓	↓
Manufacturing Process	Design Alternatives	Process Controls
↓		
Production Requirements		

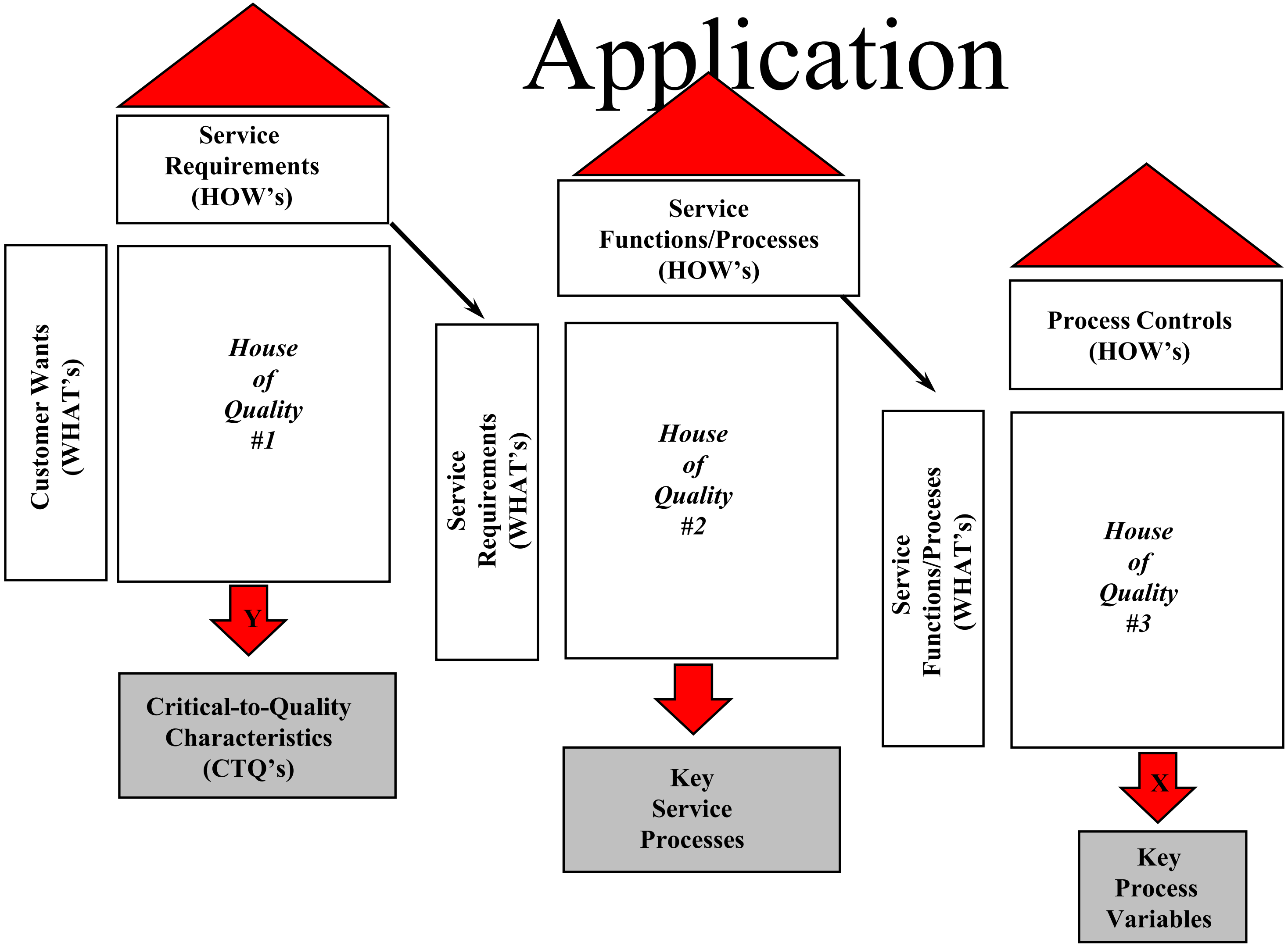
Levels Of Granularity

Flowdown Relates The Houses To Each Other

QFD Flowdown–Product Application



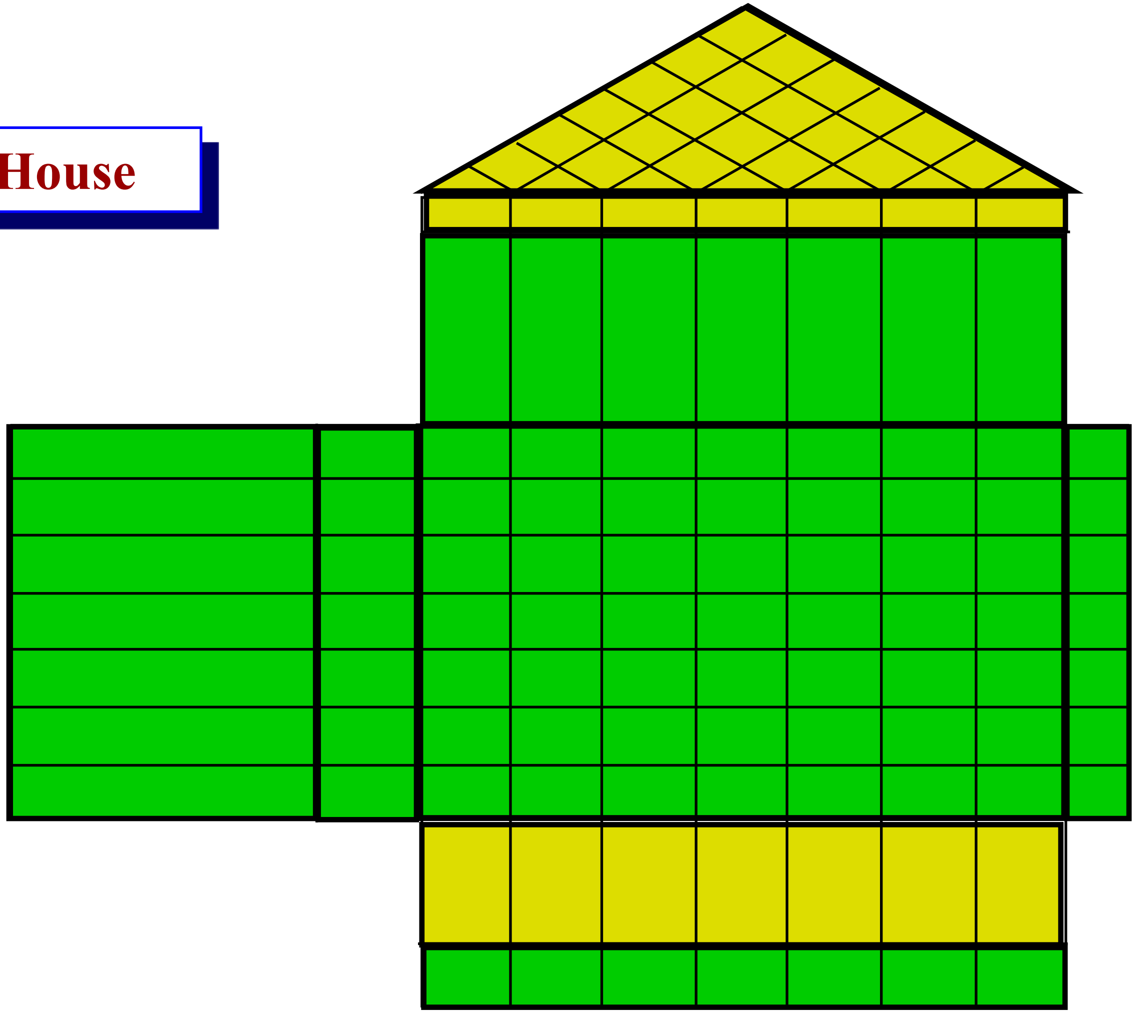
QFD Flowdown–Services Application



THE BASIC HOUSE OF QUALITY

Two Element Types In Each House

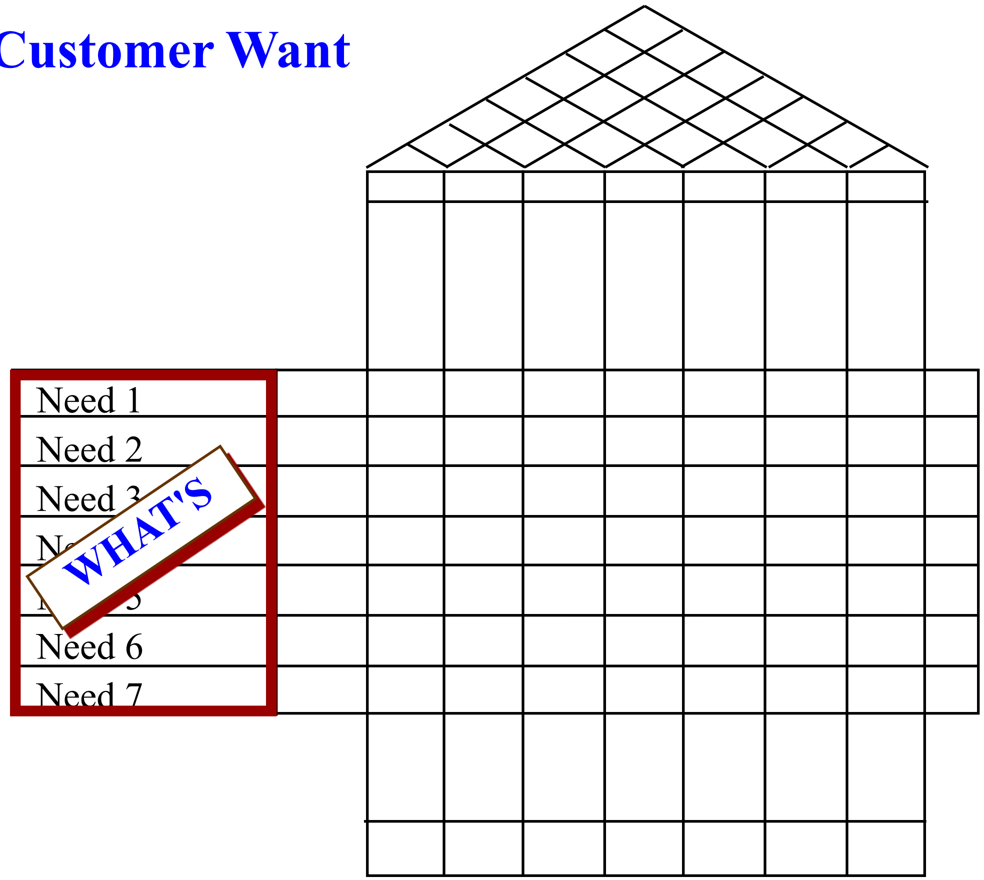
- KEY ELEMENTS
- INFORMATIONAL ELEMENTS



Voice of the Customer

KEY ELEMENTS - “WHAT’S”

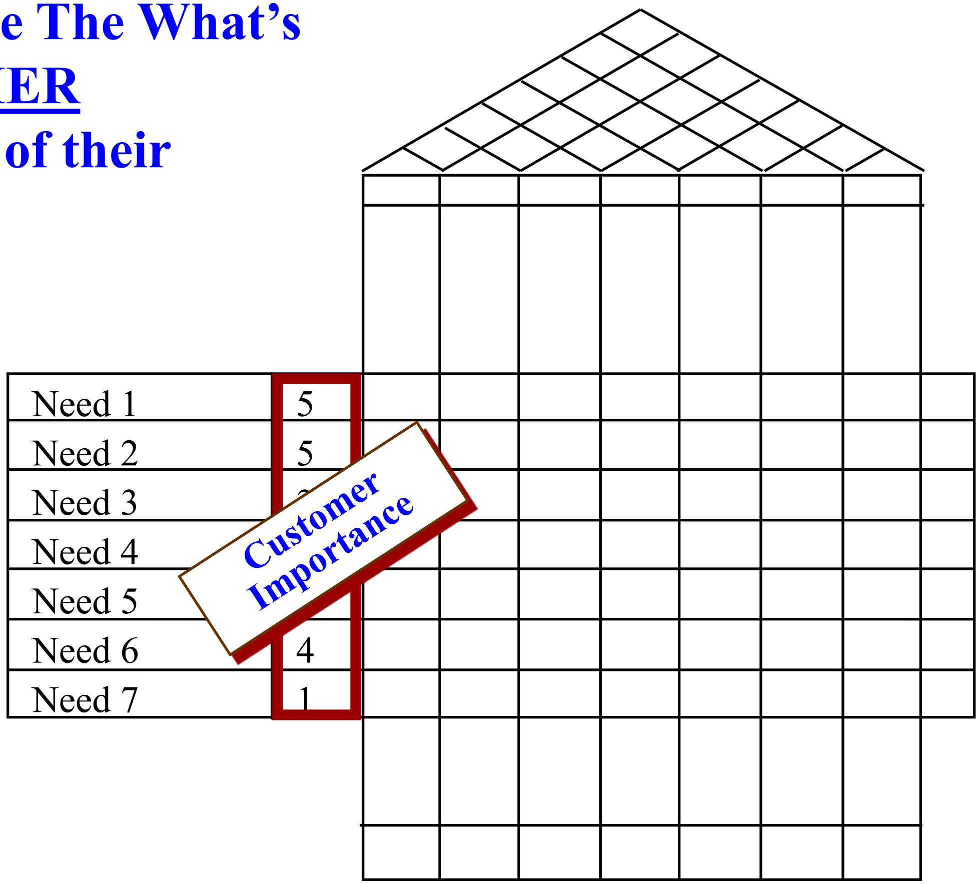
- **What Does The Customer Want**
- **Customer Needs**
- **CTQs**
- **Ys**



Voice of the Customer

KEY ELEMENTS - CUSTOMER IMPORTANCE

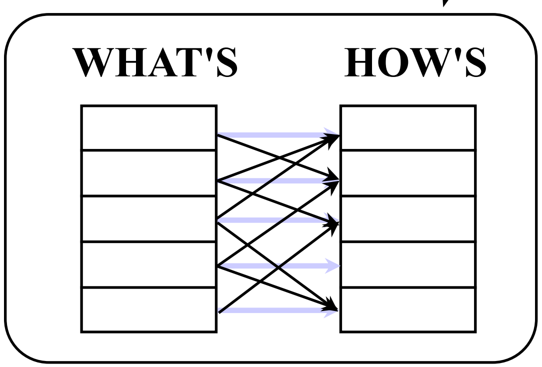
- **How Important Are The What's <u>TO THE CUSTOMER</u>**
- **Customer Ranking of their Needs**

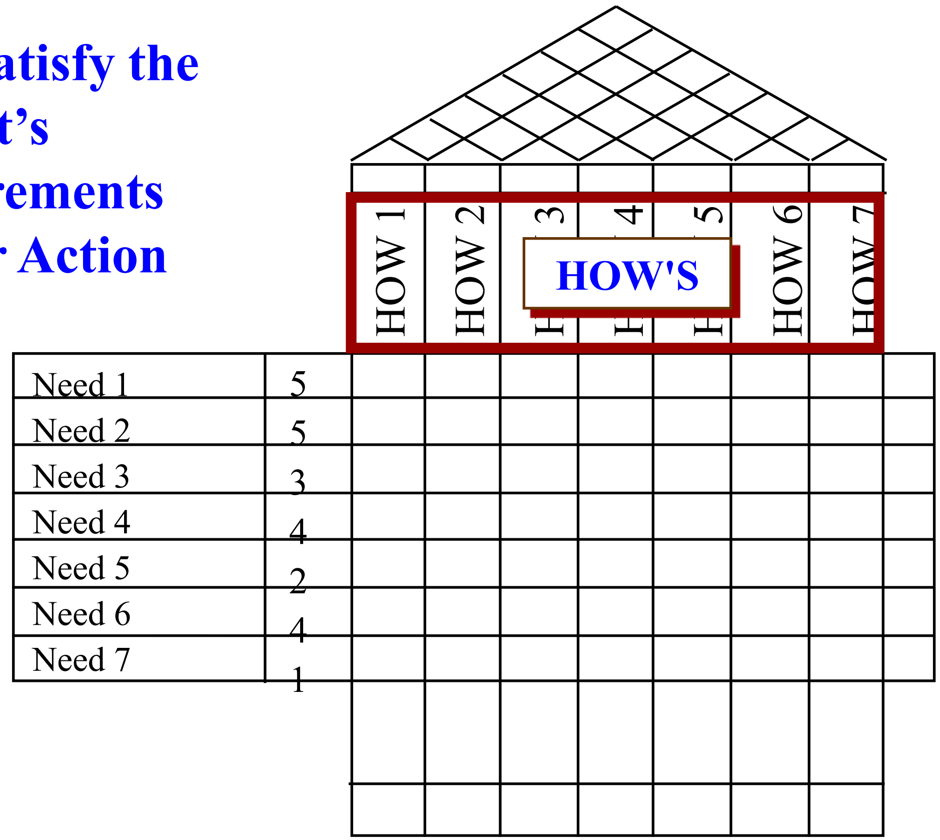


Satisfy the Customer Needs

KEY ELEMENTS - “HOW’S”

- How Do You Satisfy the Customer What’s
- Product Requirements
- Translation For Action
- Xs

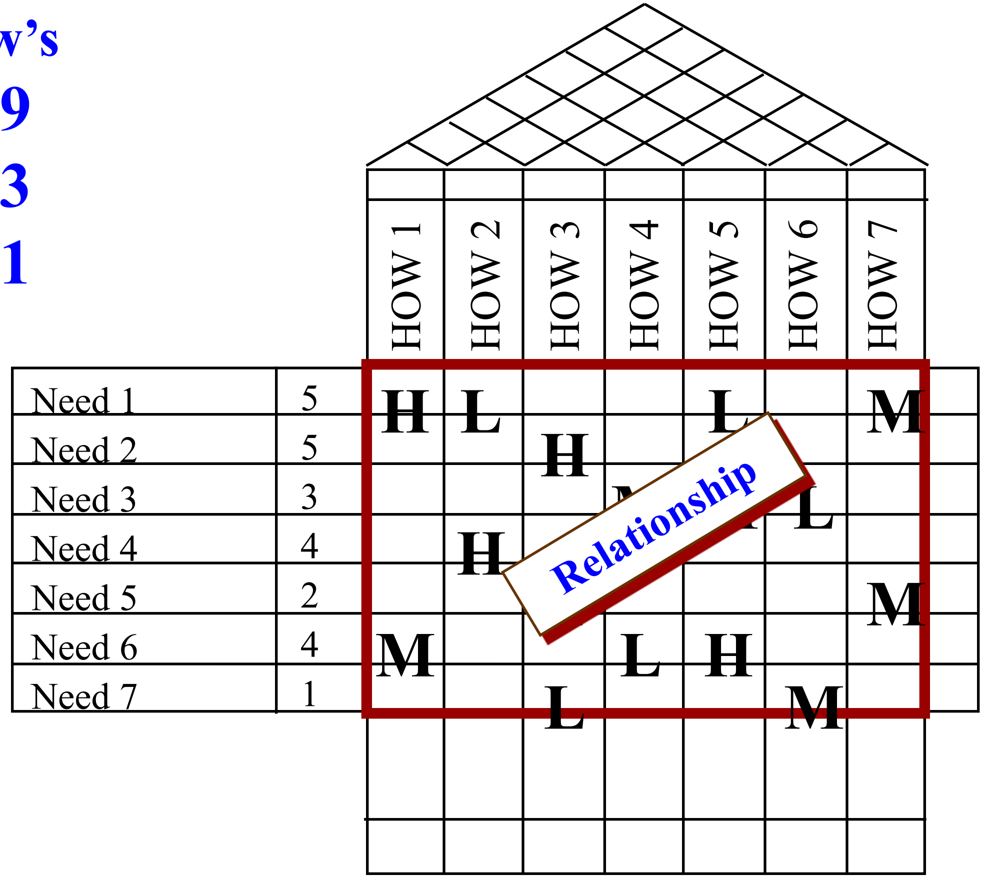




Relating WHATs to the HOWs

KEY ELEMENTS - RELATIONSHIP

- Strength of the Interrelation Between the What's and the How's
  - H Strong 9
  - M Medium 3
  - L Weak 1
- Transfer Function
- Y = f(X)



Ranking The HOW'S

KEY ELEMENTS - TECH. IMPORTANCE

- Which How's are Key
- Where Should The Focus Lie

		HOW 1	HOW 2	HOW 3	HOW 4	HOW 5	HOW 6	HOW 7
Need 1	CI	45	5			5		15
Need 2	5			45				
Need 3	3				9	9	3	
Need 4	4		36					
Need 5	2			2				6
Need 6	4	12			4	36		
Need 7	1			1			M	
		57	41	48	13	50	6	21

Technical Importance

- $TI = \sum_{column} (CI * Strength)$

QFD Opportunity

- QFD is an opportunity to really listen:
  - The customer knows what they want
  - They often don't directly verbalize
  - Extra information surfaces
  - Watch for what they say they don't want
- Understand the types of needs of customers
  - What does the customer voice?
- The Voice of the Customer (VOC) is also a process
  - VOC is the independent process
  - QFD is the dependent process

Examples of QFD

Converting VOC to QFD

Translating Whats to Hows

Identify the Functions or Processes that Impact Customer Wants

that Impact Customer Wants

What

Hows

What		Sales	Project Management	Engineering	Manufacturing	Sourcing	Partners	Field Engineer
Responsiveness to the Customer	5							
Price & Product Competitiveness	3							
Hardware Quality	5							
Hardware On Time Delivery	4							
Software Quality	3							
Software On Time Delivery	4							
Contract Understanding	3							
Product Performance	4							

Converting VOC to QFD

The Relationship Between What & How

Relationships

Direct & Strong = 9
Direct = 3
Indirect = 1

Evaluate the Impact of Each Function/Process on the Customer Wants

What		Sales	Project Management	Engineering	Manufacturing	Sourcing	Partners	Field Engineer
Responsiveness to the Customer	5	*9*	*9*	*9*	*3*	*1*	*3*	*9*
Price & Product Competitiveness	3	*9*		*9*	*9*			
Hardware Quality	5			*3*	*9*	*9*	*3*	*9*
Hardware On Time Delivery	4	*1*	*3*	*3*	*9*	*9*	*3*	
Software Quality	3			*9*	*3*	*3*		*3*
Software On Time Delivery	4		*3*	*9*		*3*	*3*	*1*
Contract Understanding	3	*9*	*9*	*9*			*3*	*1*
Product Performance	4	*3*		*9*	*3*		*3*	*9*

Converting VOC to QFD

Qualifying Importance

What		Sales	Project Management	*Engineering*	*Manufacturing*	Sourcing	Partners	*Field Engineer*
Responsiveness to the Customer	5	9	9	9	3	1	3	9
Price & Product Competitiveness	3	9		9	9			
Hardware Quality	5			3	9	9	3	9
Hardware On Time Delivery	4	1	3	3	9	9	3	
Software Quality	3			9	3	3		3
Software On Time Delivery	4		3	9		3	3	1
Contract Understanding	3	9	9	9			3	1
Product Performance	4	3		9	3		3	9
		115	96	***225***	***144***	107	75	***142***

Functions

Calculate the overall magnitude of the impact each function/process has on the customer wants

QFD exercise

OK, Let's Walk Through A Simple Example

QFD Example
An Automobile Bumper

Customer Request:

There is too much damage to bumpers in low-speed collisions. Customer wants a better bumper.

QFD Example
An Automobile Bumper

Step 2: Determine Customer Requirements/Constraints

- I want something that looks nice (basic)
- It must hold my license plate (performance)
- I want it strong enough not to dent (excitement)
- It must protect my tail-lights and head-lights (performance)
- I don‟t want to pay too much (basic)

QFD Example
An Automobile Bumper

: Translate Customer Requirements into Measurable Engineering Specifications and define target values

- Specify how license plate will be held
- Specify how to resist dents through material yield strength, young's modulus, etc.
- Specify with a dollar amount the term „inexpensive"

QFD Example
An Automobile Bumper

Customer Requirements	yield strength	Young's Modulus	mounting hole separation	plating thickness	effective spring constant	cross-section moment of inertia	weight	max. deflection	cost	Competitor A	Competitor B	Competitor C
looks good				X						2	4	3
holds license plate			X							5	5	1
resists dents	X	X								3	3	5
protects lights	X	X			X	X		X		3	3	5
doesn't rust				X						5	5	2
lasts a long time				X						4	4	4
inexpensive	X			X			X		X	4	3	2
protects fender/hood	X	X			X	X		X		3	3	5
Engineering Targets				0.05			50		100			
Units	psi	psi	in.	in.	lb/in.	in^4	lb	in.	$			

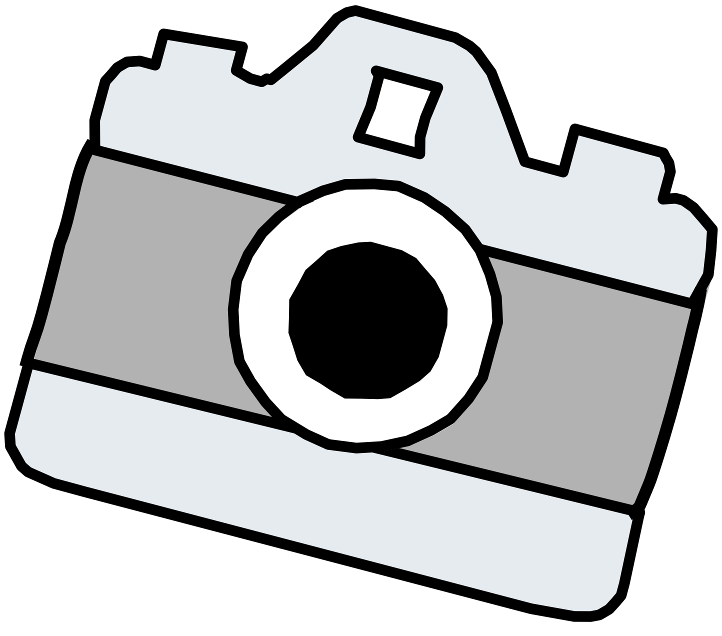
Engineering Requirements

Benchmarks

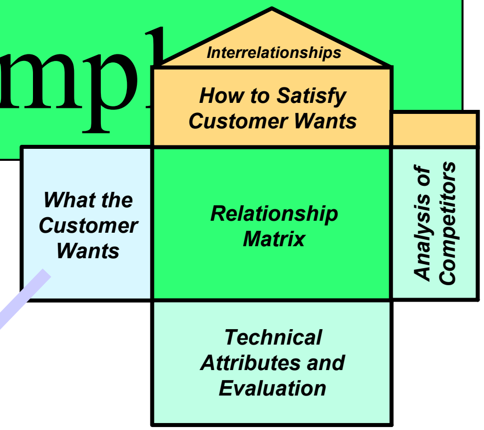
House of Quality Example

Your team has been charged with designing a new camera for Great Cameras, Inc.

The first action is to construct a House of Quality



House of Quality Example

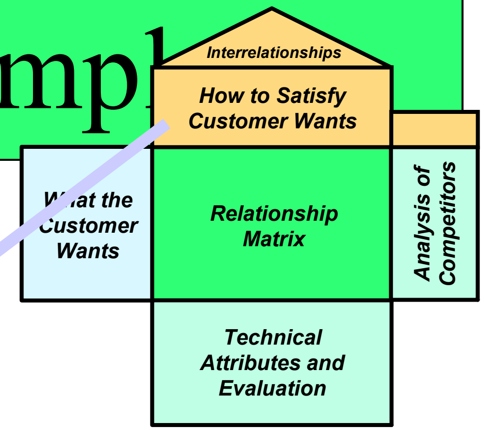


What the customer wants

Customer importance rating (5 = highest)

Lightweight	*3*
Easy to use	*4*
Reliable	*5*
Easy to hold steady	*2*
Color correction	*1*

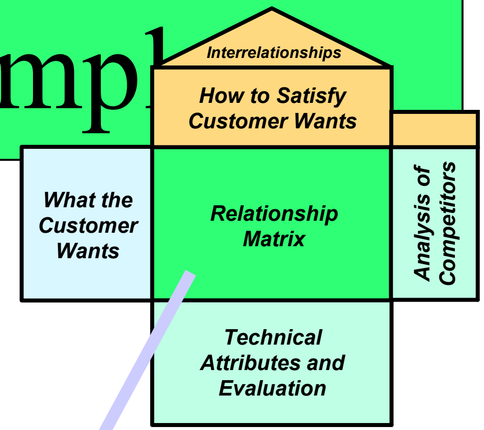
House of Quality Example



Low electricity requirements	*Aluminum components*	*Auto focus*	*Auto exposure*	*Paint pallet*	*Ergonomic design*

How to Satisfy Customer Wants

House of Quality Example



◉ *High relationship*

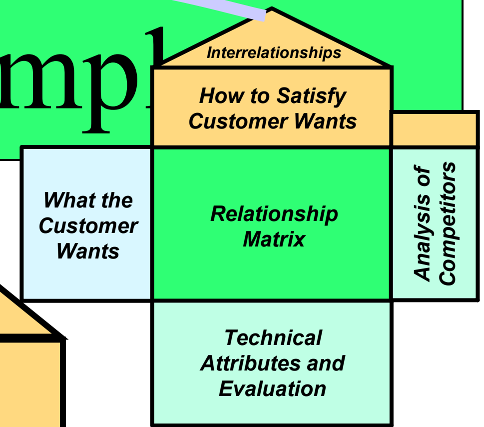
○ *Medium relationship*

• *Low relationship*

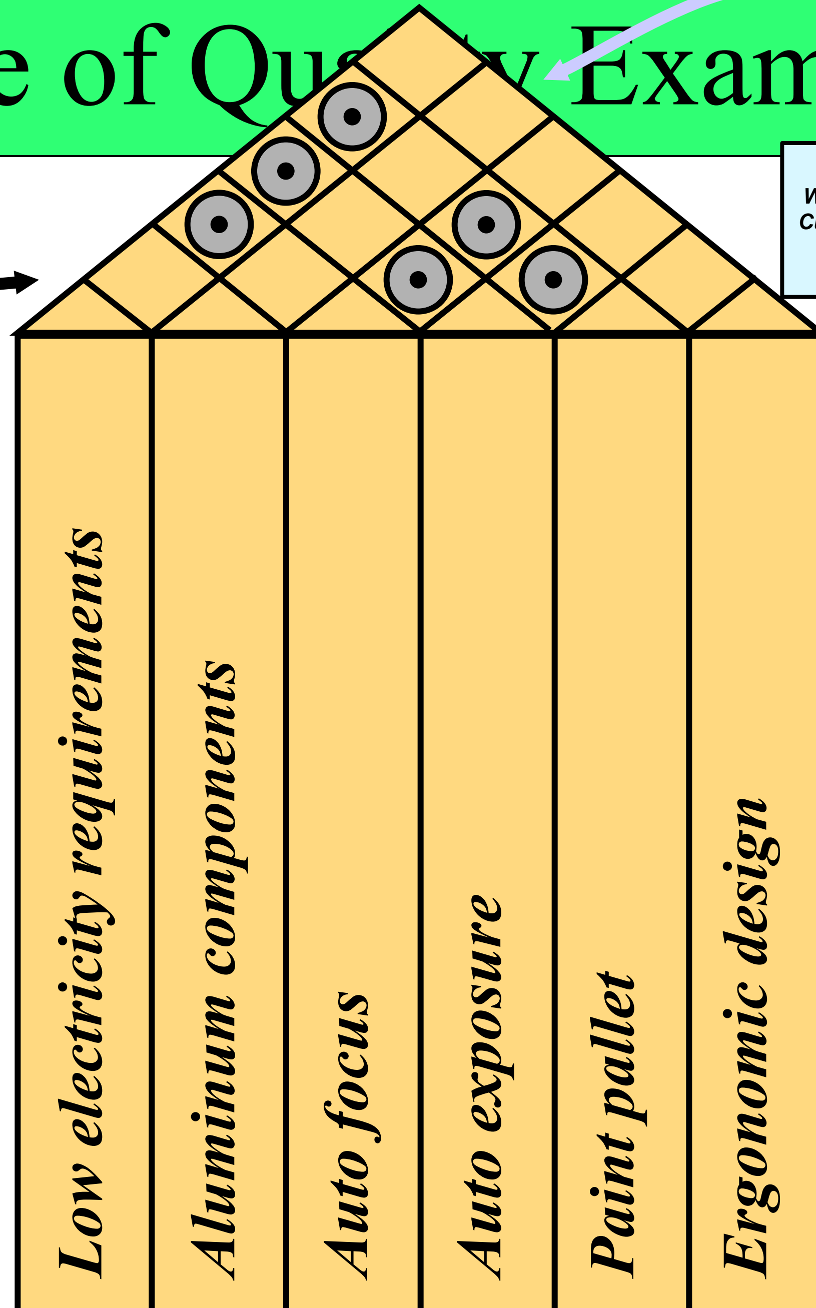
Lightweight	*3*	•	○				•
Easy to use	*4*	•		○	○	○	○
Reliable	*5*	○		○	○	○	
Easy to hold steady	*2*						◉
Color corrections	*1*					◉	

Relationship matrix

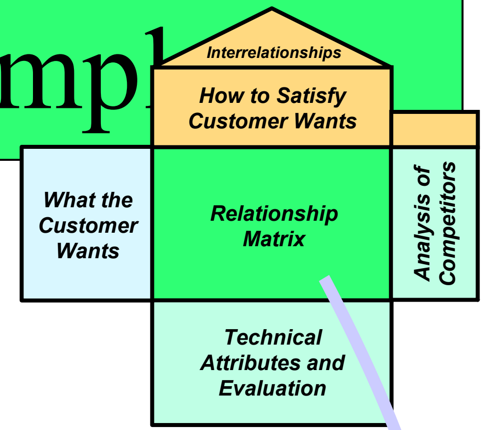
House of Quality Example



Relationships between the things we can do



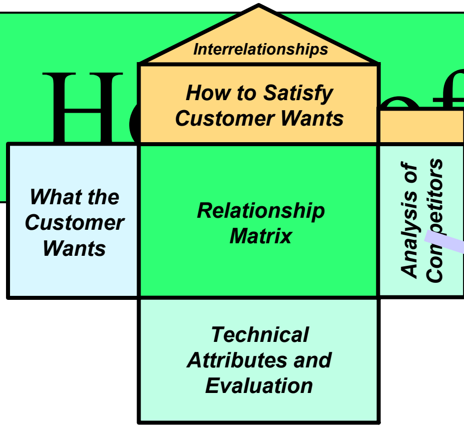
House of Quality Example



Lightweight	3	•	○				•
Easy to use	4	•		○	○	○	○
Reliable	5	○		○	○	○	
Easy to hold steady	2						◉
Color corrections	1					◉	
Our importance ratings		22	9	27	27	32	25

Weighted rating

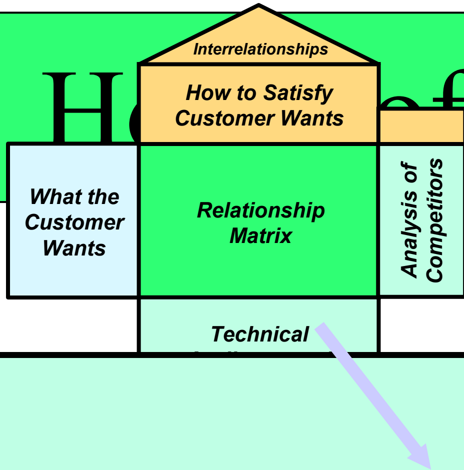
House of Quality Example



How well do competing products meet customer wants

				Company A	*Company B*
Lightweight	3	•	•	*G*	*P*
Easy to use	4	•	◯	*G*	*P*
Reliable	5	◯		*F*	*G*
Easy to hold steady	2			*G*	*P*
Color corrections	1			*P*	*P*
Our importance ratings		22	5		

House of Quality Example



Target values (Technical attributes)		**0.5 A**	**75%**	**2' to ∞**	**2 circuits**	***Failure 1 per 10,000***	***Panel ranking***
Technical evaluation	***Company A***	**0.7**	**60%**	***yes***	**1**	***ok***	***G***
	Company B	**0.6**	**50%**	***yes***	**2**	***ok***	***F***
	Us	**0.5**	**75%**	***yes***	**2**	***ok***	***G***

House of Quality Exa

Completed House of Quality

		Low electricity requirements	Aluminum components	Auto focus	Auto exposure	Paint pallet	Ergonomic design	Company A	Company B
Lightweight	***3***	•	○				•	***G***	***P***
Easy to use	***4***	•		○	○	○	○	***G***	***P***
Reliable	***5***	○		○	○	○		***F***	***G***
Easy to hold steady	***2***						◉	***G***	***P***
Color correction	***1***					◉		***P***	***P***
Our importance ratings		22	9	27	27	32	25		
Target values (Technical attributes)		*0.5 A*	*75%*	*2' to ∞*	*2 circuits*	*Failure 1 per 10,000*	*Panel ranking*		
Technical evaluation	*Company A*	0.7	60%	*yes*	1	*ok*	*G*		
	Company B	0.6	50%	*yes*	2	*ok*	*F*		
	Us	0.5	75%	*yes*	2	*ok*	*G*		

Measure

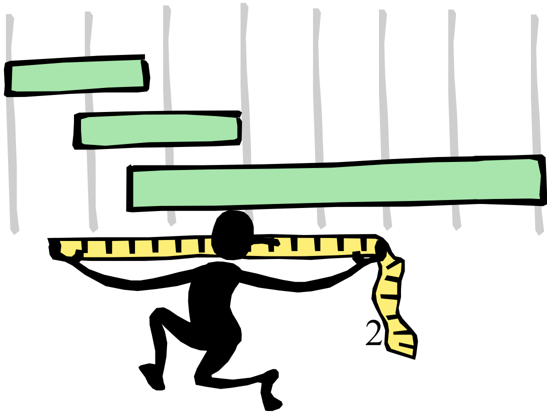
Lean Six Sigma Green Belt

by
Rajiv Purkayastha
Six sigma MBB

Measure Phase Overview

Why is the Measure phase important?

This phase is important because it ensures that accurate and reliable data is collected to measure current process performance related to the customer CTQ.



Selecting CTQ Characteristics

Two tools are commonly used to determine CTQs

- ➢CTQ Drill Down Tree
- ➢Quality Function Deployment (QFD)

Define Performance Standards

What are the project tasks for completing Measure 5?

Develop operational definition for process to be measured

Identify target performance

Set specification limit(s)

Define unit, defect and defect opportunity

Performance Standard

Performance Standards					
CTQ Measure	Data Type	Operational Definition	Upper Specification	Target	Segmentation Factors
Lead Time to close sev 1 tickets	Continuous	Lead Time to close sev 1 ticket = (Ticket closing time - Ticket opening time)	2 hrs	Same as upper specification	1. Lead time to generate OCN from P.O. date 2. Lead time to allocate resource from date of OCN generation 3. Lead time to provision the link from date of allocation of resource 4. Lead time to test the link after provisioning date 5. Lead time for LCR signoff from testing date 6. Lead time to generate first time Bill

Operational Definitions is a precise description that tells how to get a value for the characteristics (CTQ) we are trying to measure. It includes " what something is" and How to measure it"

Operational Definition

An Operational Definition is a precise description that tells how to get a value for the characteristic (CTQ) you are trying to measure.

It includes “what something is” and “how to measure it”.

Having an Operational Definition→

- ✓ Will remove any ambiguity in the understanding of the CTQ
- ✓ Will give a clear method to measure the CTQ
- ✓ Will ensure that everyone has the same understanding on what to measure & how to measure

At a minimum, a clear definition of defect is required

What Is an Operational Definition?

A definition that gives communicable meaning to a concept by specifying how the concept is measured and applied within a particular set of circumstances.

(Deming, ***1986***)

Develop Operational Definitions

What is an Operational Definition?

An Operational Definition gives communicable meaning to a concept by specifying how the concept is measured and applied within a particular set of circumstances.

This definition highlights two important things about an Operational Definition :

It gives a precise meaning to the spoken or written word, forming a "common

language" between two or more people. It defines how a word or phrase is used when it is applied in a specific context. This implies that words may have different meanings when used in different situations.

For example, the Operational Definition of “count cars outside" can vary depending on who understands what from it.

Develop Operational Definitions

- To remove ambiguity
  - »Everyone has a consistent understanding
- To provide a clear way to measure the characteristic
  - »Identifies what to measure
  - »Identifies how to measure it
  - »Makes sure that no matter who does the measuring, the results are consistent

Operational Definitions : Case Study

•A large computer manufacturer needs to improve its competitiveness

•Target : reducing the cycle time for one of its latest products

•Existing data revealed it took 5-10 days to fulfill orders

•Management‟s goal : 95% of orders for this product filled within 3 days

•Results from regional plants were obtained for several months

Factory	% fulfilled within 3 days
1	73%
2	47%
3	83%
4	67%

"Heads should roll in Factory 2, right?"

Operational Definitions : Case Study

•The company found that the manufacturing plants defined “orders filled within 3 days” differently

•Factory 2 counted the day the order was placed as Day 1. The other factories counted the day *after* the order was placed as Day 1. When factory 2 recalculated its performance rate the same way as the other factories its numbers jumped up to 77%.

Factory	% fulfilled within 3 days
1	73%
2	47% = 77% when calculated the same
3	83% way as other factories
4	67%

Operations Definitions : Scale of Scrutiny

Choosing The Level Of Measurement

- Measure one scale or level smaller than what your customer measures
  - For Example:
    - If your customer measures cycle time in days, your scale of scrutiny would be hours
    - If your customer measures cycle time in hours, your scale of scrutiny would be in minutes
    - Scale of scrutiny may expose larger true variation

Operational Definition

Operational Definition Exercise

1. On-time Arrival of flight.
2. Server Downtime

1.4 Understand Data Characteristics

Why Collect Data?

- Successful organizations have a common language to communicate
- Common language promotes objectivity in decision-making process
- Don‟t come up with great solutions for problems that don‟t exist
- A measure of „where we are‟ is critical to determining „where we should be‟
- Have you reached where you intended to? -- only data answers that question
- A good data collection simplifies the problem solving effort
- If the solution costs more than the problem, it‟s not worth it. A good data collection should concentrate as much on measuring problems as it does on measuring solutions

Usage of Data

- Data is used to classify, describe, improve & control – objects & situations

- Data provides an informative description of products and processes

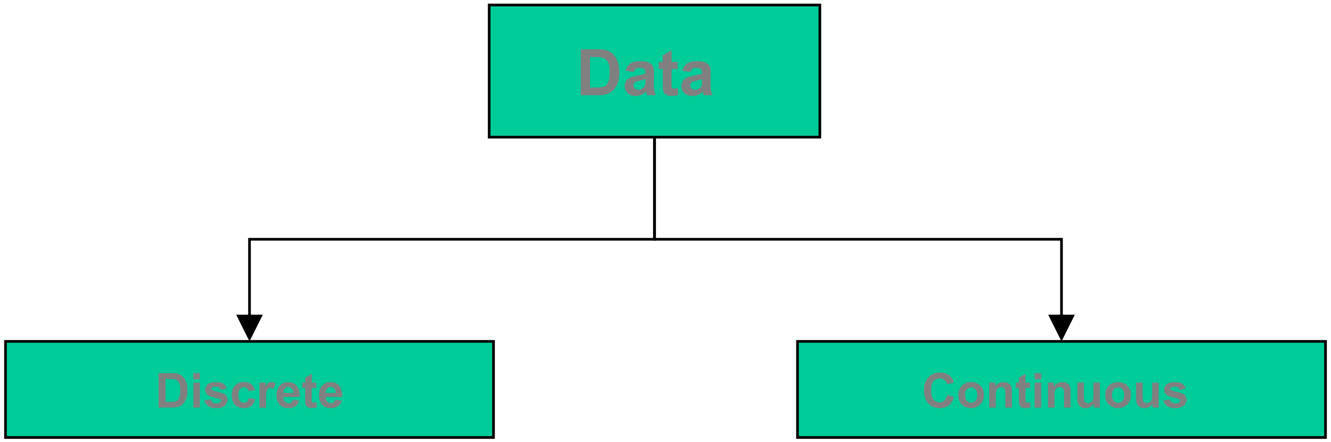
- Data is derived from objects & situations in the form of measurement

- A measurement system is the tool / machine / method used to measure data

Key Concepts

- Improvement can only occur if we understand where we are & where to go, supported by a measurement system that validates both situations
- If the tool, by which we measure a characteristic, is not appropriate, able, or accurate, effective improvement will not occur
- One must understand and quantify the measurement system

Data Types



Discrete

- Data that can be categorized into a fixed number of classes
- That comes mostly in the form of choices as yes / no, ok / not Ok
- That cannot be measured but can be categorized

Continuous

- Data that can be categorized into infinite number of classes
- That can assume any value between two given values
- That can be measured using some equipment or otherwise

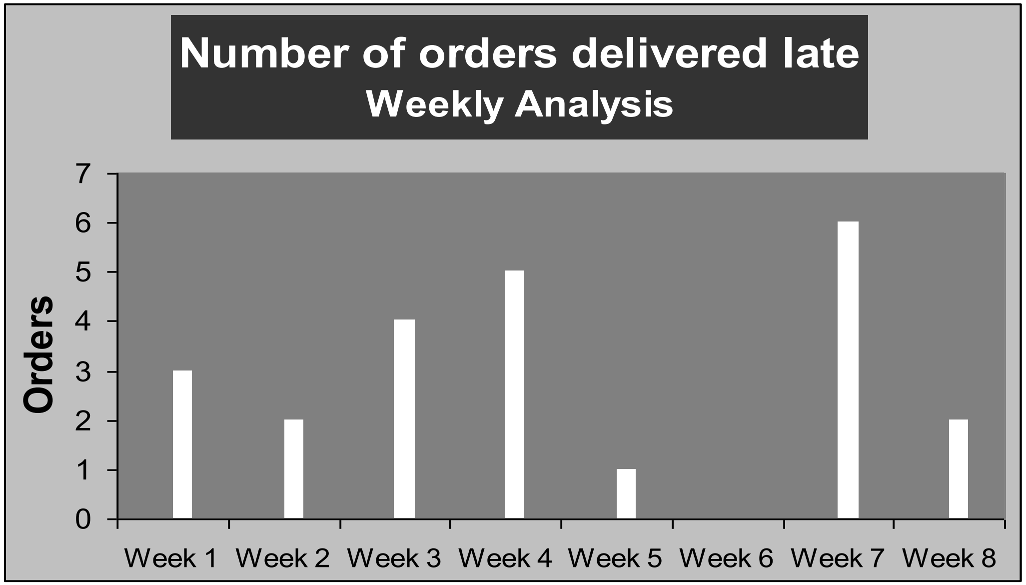
Types of Data

- **Discrete data**
  - Data that can take a limited number of values
  - Examples
    - Number of orders delivered late
    - Number of days to resolve a problem
    - Number of „yes" responses to a satisfaction survey
    - Number of matches won by Indian cricket team
- **Continuous Data**
  - Data that be expressed in either fractions or whole numbers
  - Examples

    Number of possible data points between 5 & 100
    - Temperature of the room
    - Exchange rate of a currency

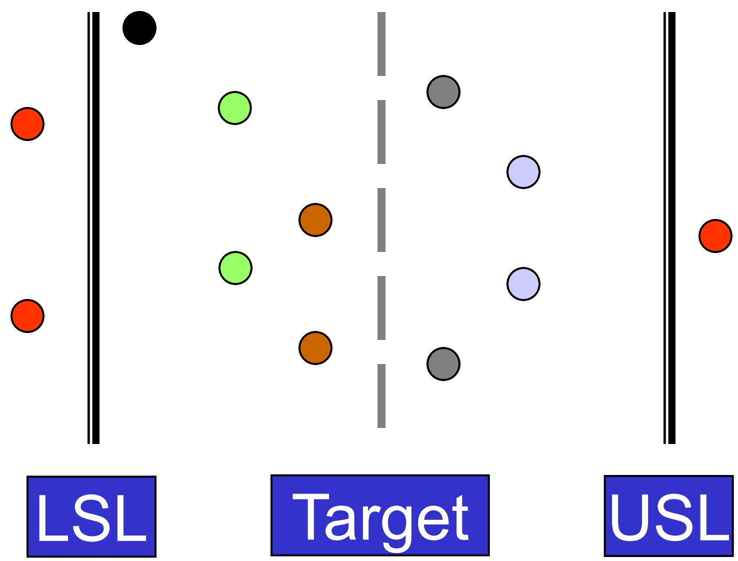
Discrete Data Characteristics

Responses to the Satisfaction Survey	Satisfied	Not Satisfied
Top Management	15	2
Senior Management	25	3
Middle Management	250	15
Contract Employees	500	52



What is a Specification?

- A specification is a customer-defined tolerance for the unit characteristics
- There may be two-sided specifications
- Specifications form the basis of any defect measurement exercise



USL: Upper Specification Limit for a Performance Parameter, anything above this is a defect.

LSL: Lower Specification Limit for a Performance Parameter, anything below this is a defect.

Target: Ideally the middle point of USL & LSL.

Examples

- Ticket booking example
  - Unit: each ticket received by customer
  - Defect definition: a ticket with wrong booking
    a ticket not legible enough
    a ticket given after 30 minutes

  Defective ticket

  Pizza delivery example
  - Unit: each order placed
  - Defect definition: an order delivered after 20 minutes
    an order not delivered hot
    an order not delivered with salt & pepper
    an order not delivered at all

Unit, Opportunity and Defect

A Unit *is the number of parts, sub-assemblies, assemblies or systems inspected or tested.*

An Opportunity *is a characteristic you inspect or test*

A Defect *is anything that results in customer dissatisfaction / any non conformance*

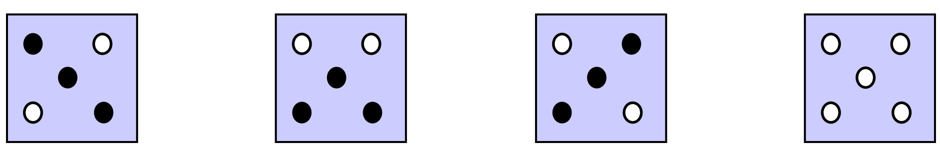
In the example below:
The Customer ordered for squares with 5 white circles etched on the surface

Therefore:

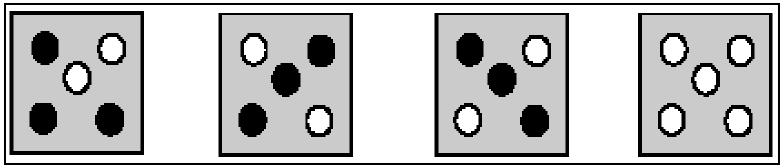
Each square is a ***UNIT***
Each circle is an ***OPPORTUNITY***
Each black circle is a ***DEFECT***

Therefore we have:
4 Units
5 Opportunities per Unit
9 Defects
3 Defectives

TOP or Total Opportunity is the product of Number of Units with the Number of Opportunities



Defects per million opportunity



Formulas

Defects per Unit

- DPU = D/U
- 9/4 = 2.25

Total Opportunities

- TOP = U*OP
- 4*5 = 20

Defects per Opportunity (Probability of a Defect)

- DPO = D/TOP
- 9/20 = .45

Defects per Million Opportunities

- DPMO = DPO*1,000,000
- .45*1,000,000 = 450,000

Unit, Defect & Defect Opportunity

Unit: The Item produced or processed

Ex: Code

Defect: Any event that does not meet the specifications of CTQ (It results in customer dissatisfaction)

Ex: Delayed Delivery, Poor Program Performance

Defective: A Unit with one or more defects

Ex: Code

DPU: Defect Per Unit

Opportunity: Any measurable event that provide a chance of not meeting specifications of CTQ

EX: No of types of defects

DPMO: Defect Per Million opportunities

Cont….

Unit, Defect & Defect Opportunity→ Example

Unit → : A Code of 30 Lines

Defect Opportunities → 30 (Number of lines)

Defects→ 2

DPU → No. Of Defects / No. of Units = 2/1 = 2

DPO→ Defects Per Opportunity

$$= \frac{\text{Number of Defects}}{\text{Total number of opportunities}}$$

$$= 2/30 = 0.066666666$$

DPMO→ Defects Per Opportunity X 10^6

$$= 0.067 * 10^6 = 66666.67 \text{ DPMO}$$

The Item produced or processed
The Item produced or processed
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The Item produced or processed
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30 Lines of Code

Cont….

Sigma Conversion Table

Long-Term Yield	Process Sigma (ST)	Defects Per 1,000,000	Defects Per 100,000	Defects Per 10,000	Defects Per 1,000	Defects Per 100
99.99966%	6.0	3.4	0.34	0.034	0.0034	0.00034
99.9995%	5.9	5	0.5	0.05	0.005	0.0005
99.9992%	5.8	8	0.8	0.08	0.008	0.0008
99.9990%	5.7	10	1	0.1	0.01	0.001
99.9980%	5.6	20	2	0.2	0.02	0.002
99.9970%	5.5	30	3	0.3	0.03	0.003
99.9960%	5.4	40	4	0.4	0.04	0.004
99.9930%	5.3	70	7	0.7	0.07	0.007
99.9900%	5.2	100	10	1.0	0.1	0.01
99.9850%	5.1	150	15	1.5	0.15	0.015
99.9770%	5.0	230	23	2.3	0.23	0.023
99.9670%	4.9	330	33	3.3	0.33	0.033
99.9520%	4.8	480	48	4.8	0.48	0.048
99.9320%	4.7	680	68	6.8	0.68	0.068
99.9040%	4.6	960	96	9.6	0.96	0.096
99.8650%	4.5	1,350	135	13.5	1.35	0.135
99.8140%	4.4	1,860	186	18.6	1.86	0.186
99.7450%	4.3	2,550	255	25.5	2.55	0.255
99.6540%	4.2	3,460	346	34.6	3.46	0.346
99.5340%	4.1	4,660	466	46.6	4.66	0.466
99.3790%	4.0	6,210	621	62.1	6.21	0.621
99.1810%	3.9	8,190	819	81.9	8.19	0.819
98.930%	3.8	10,700	1,070	107	10.7	1.07
98.610%	3.7	13,900	1,390	139	13.9	1.39
98.220%	3.6	17,800	1,780	178	17.8	1.78
97.730%	3.5	22,700	2,270	227	22.7	2.27
97.130%	3.4	28,700	2,870	287	28.7	2.87
96.410%	3.3	35,900	3,590	359	35.9	3.59
95.540%	3.2	44,600	4,460	446	44.6	4.46
94.520%	3.1	54,800	5,480	548	54.8	5.48
93.320%	3.0	66,800	6,680	668	66.8	6.68

Cont….

Sigma Conversion Table

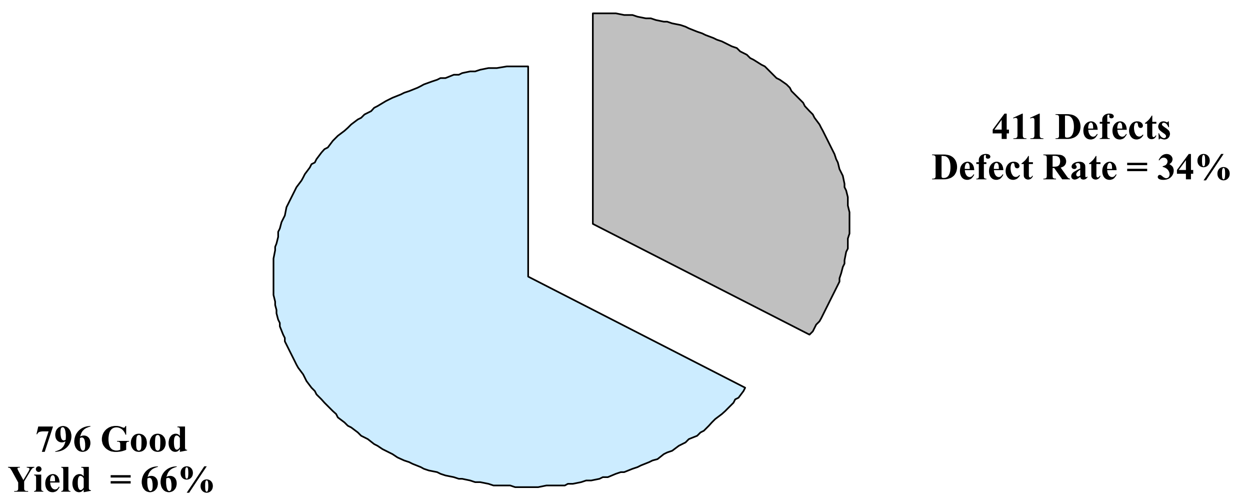
Long-Term Yield	Process Sigma (ST)	Defects Per 1,000,000	Defects Per 100,000	Defects Per 10,000	Defects Per 1,000	Defects Per 100
91.920%	2.9	80,800	8,080	808	80.8	8.08
90.320%	2.8	96,800	9,680	968	96.8	9.68
88.50%	2.7	115,000	11,500	1,150	115	11.5
86.50%	2.6	135,000	13,500	1,350	135	13.5
84.20%	2.5	158,000	15,800	1,580	158	15.8
81.60%	2.4	184,000	18,400	1,840	184	18.4
78.80%	2.3	212,000	21,200	2,120	212	21.2
75.80%	2.2	242,000	24,200	2,420	242	24.2
72.60%	2.1	274,000	27,400	2,740	274	27.4
69.20%	2.0	308,000	30,800	3,080	308	30.8
65.60%	1.9	344,000	34,400	3,440	344	34.4
61.80%	1.8	382,000	38,200	3,820	382	38.2
58.00%	1.7	420,000	42,000	4,200	420	42
54.00%	1.6	460,000	46,000	4,600	460	46
50%	1.5	500,000	50,000	5,000	500	50
46%	1.4	540,000	54,000	5,400	540	54
43%	1.3	570,000	57,000	5,700	570	57
39%	1.2	610,000	61,000	6,100	610	61
35%	1.1	650,000	65,000	6,500	650	65
31%	1.0	690,000	69,000	6,900	690	69
28%	0.9	720,000	72,000	7,200	720	72
25%	0.8	750,000	75,000	7,500	750	75
22%	0.7	780,000	78,000	7,800	780	78
19%	0.6	810,000	81,000	8,100	810	81
16%	0.5	840,000	84,000	8,400	840	84
14%	0.4	860,000	86,000	8,600	860	86
12%	0.3	880,000	88,000	8,800	880	88
10%	0.2	900,000	90,000	9,000	900	90
8%	0.1	920,000	92,000	9,200	920	92

Note: Subtract 1.5 to get long-term sigma leve

Cont….

Yield

If we think of transactions as either defects (leading to unsatisfied customers) or good (leading to satisfied customers), then we have described the potential outcomes of the process. Another way to describe the proportion of good transactions is yield.



Total Transactions = Good + Defects
100% = Yield + Defect Rate

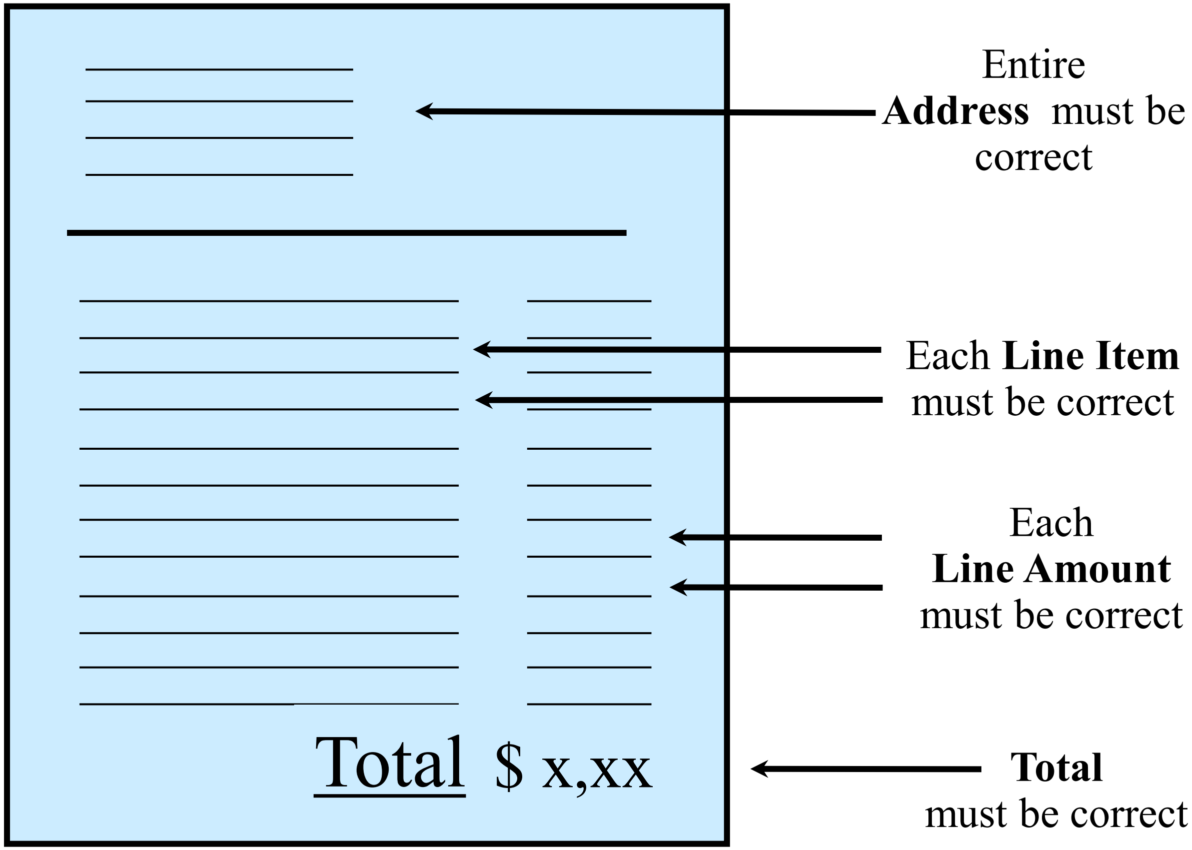
Types of Yield

Different types of Yield can impact the quality level we measure. Here are the types we will review by looking at an example of statement printings.

- Classical Yield
- First Pass Yield
- Rolled Throughput Yield

Making a Statement

Customer Statements have the following requirements…



Statement Printing Example

Four statements are printed and checked for errors. Those that contain errors are reprinted. Here are the results...

First Printing

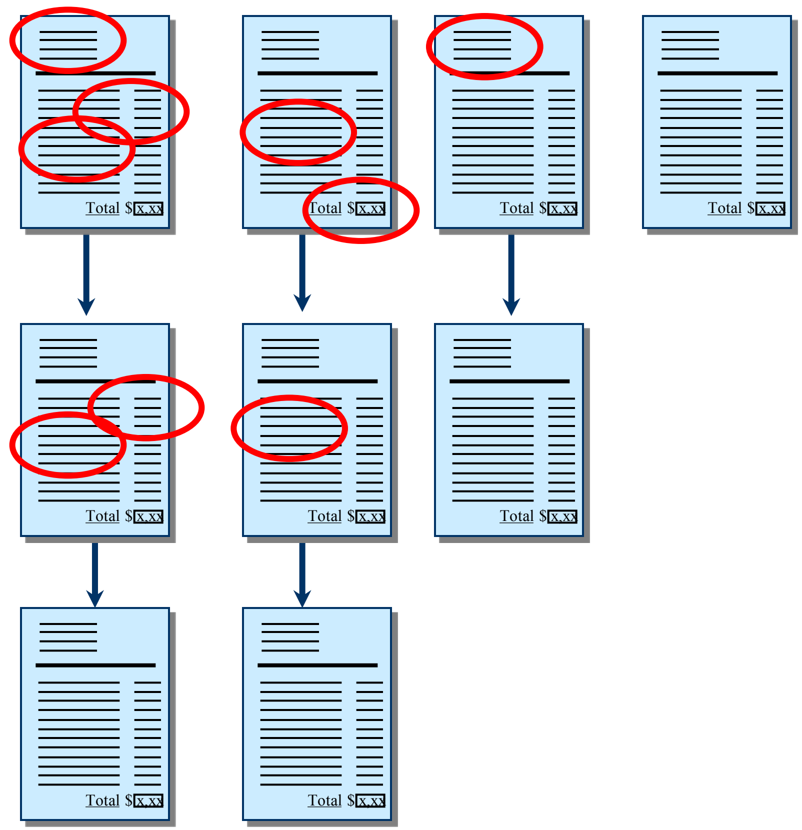
- Wrong Address = 2
- Wrong Line Item = 2
- Wrong Amount = 1
- Wrong Total = 1

Second Printing (Rework)

- Wrong Address = 0
- Wrong Line Item = 2
- Wrong Amount = 1
- Wrong Total = 0

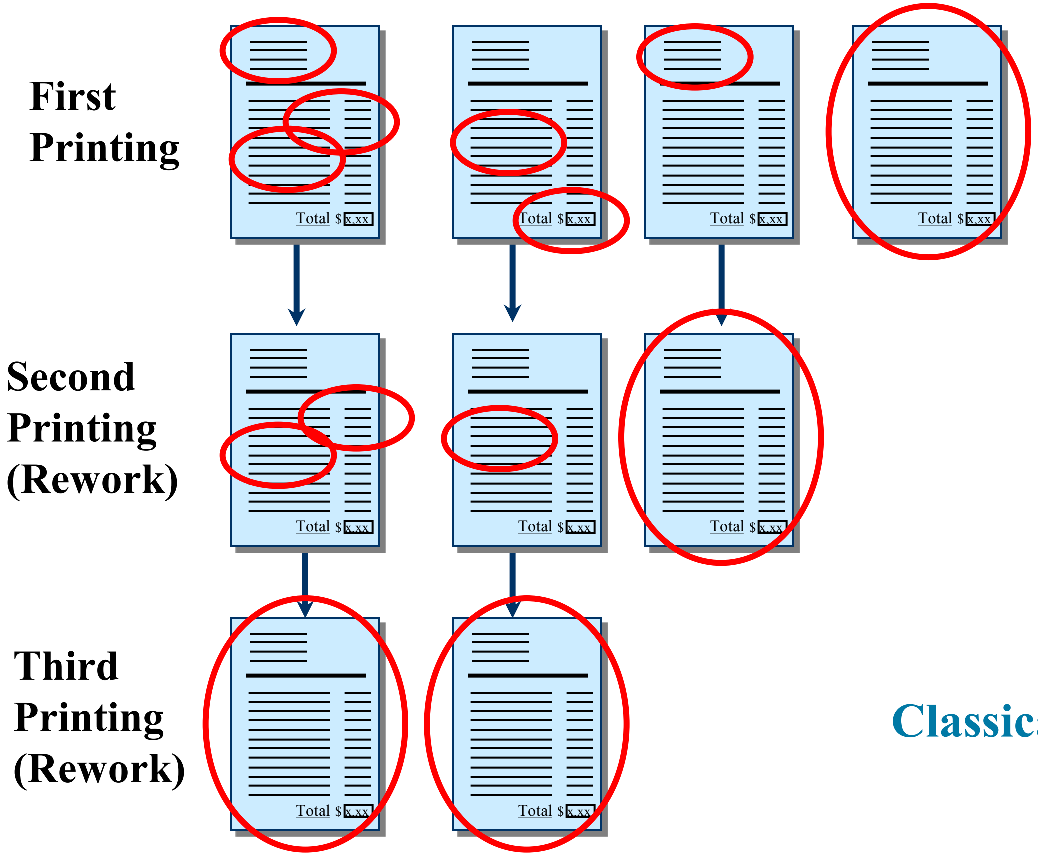
Third Printing (Rework)

- Wrong Address = 0
- Wrong Line Item = 0
- Wrong Amount = 0
- Wrong Total = 0



Classical Yield

If we count all statements that passed inspection in all three operations, our fulfillment would be 100% (four out of four). This is the probability of statements having no defects after all rework has been completed.



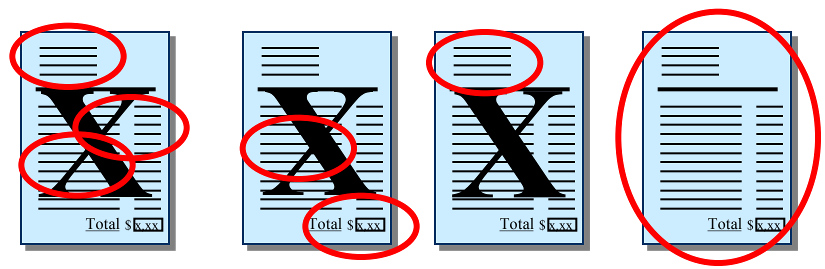
Classical Yield= 100%

Classical Yield includes statements that were reworked.

First Pass Yield

If we define our defect as statements failing to pass inspection on the first try, then our fulfillment is only 25% (one out of four). This is the probability of having no defect without rework based on the number of first-time, defect-free statements. This is a better measure of process performance than Classical Yield

First Printing



First Pass Yield= 25%

First Pass Yield gives no credit for rework

Rolled Throughput Yield

A final look at yield concerns output that involves several steps. If we know the yield of each step, we can multiply the percentages together to compute the probability that a transaction will go through all steps correctly the first time

Take Card Application

Enter Request

List of Cards to be Printed

Operation 1 → **Operation 2** → **Output**

Performance Level					
95%	**95%**	**X**	**95%**	**=**	**90.25%**
99%	**99%**	**X**	**99%**	**=**	**98.01%**

Takeaways

There are three different types of yield

1. Classical
2. First Pass / Throughput
3. Rolled Throughput

- Rolled Throughput yield is the best yield measurement to determine how your process is performing
- Adding inspectors does not guarantee better quality
- Six Sigma cannot be reached by inspection

Process Map Analysis

Why do we need a Process Map?

Table

Phone

Shadow

Pencil

stand

Paper

Pad

Wire

Ring

Pens

Why do we need a Process Map?

Process Mapping is a graphic display of steps & activities that constitute a process

Process

Every activity is a process. Anything which happens is an output of a process.

- **Shocking lessons**
  - Most people do not think in terms of processes. They would rather think in terms of isolated events.
  - When convinced of the value of thinking in terms of processes, most people still don‟t think in terms of processes.
  - The word “process” generates fear and resistance.

What is a Process?

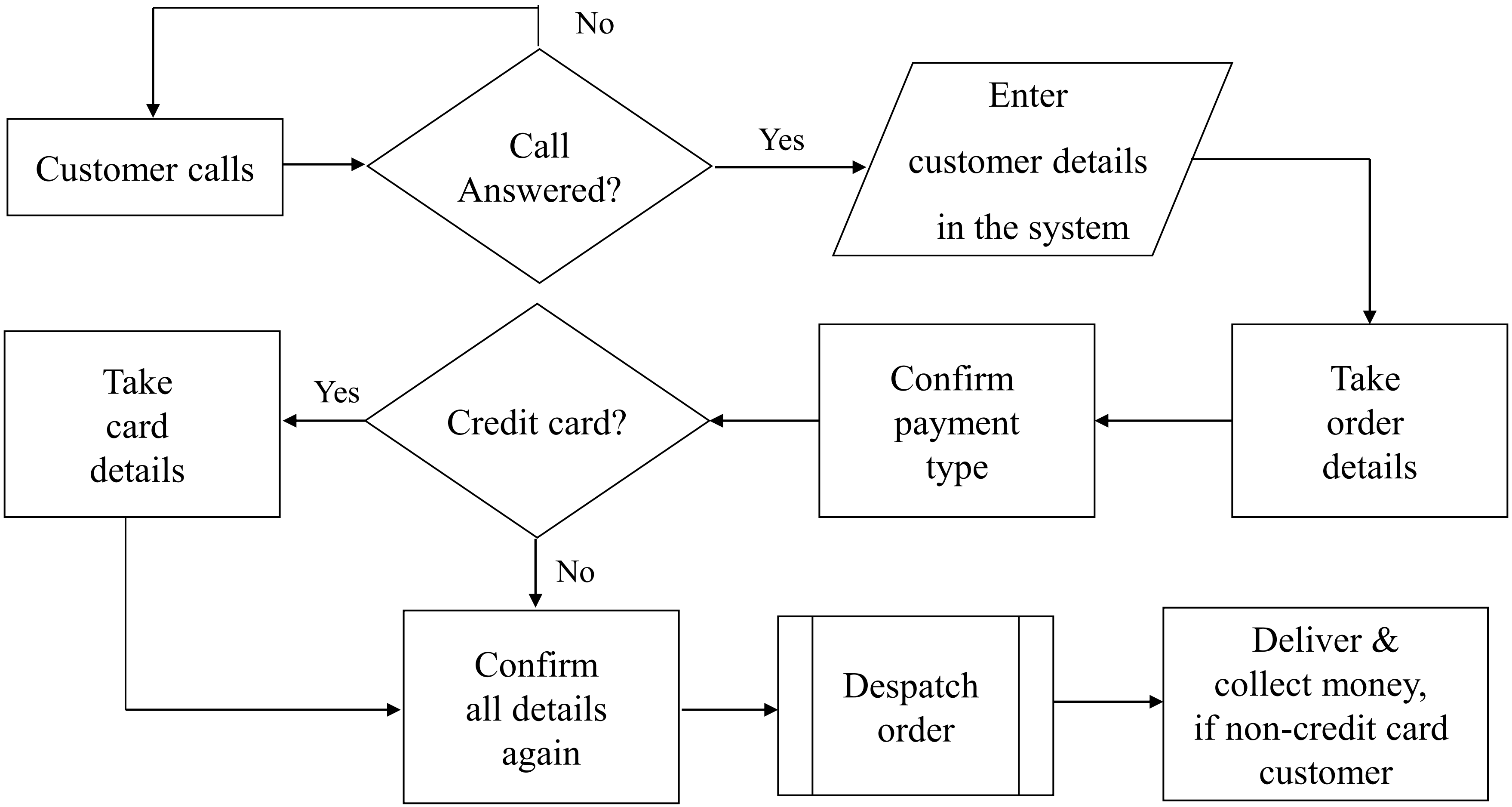
- A process is a sequence of activities performed on an input to produce an output

- A process must add value to the input

- Every process has at least one supplier & one customer

Process Mapping is as critical to a manufacturing operation as it is to a transaction

Macro Process Map of a Pizza Home Delivery

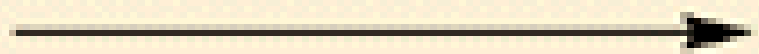
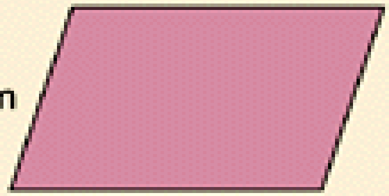
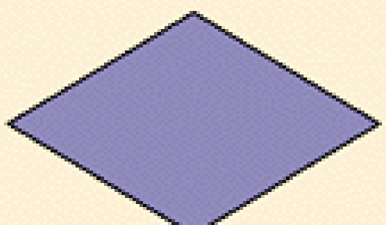


Flowcharts

What is a flowchart?

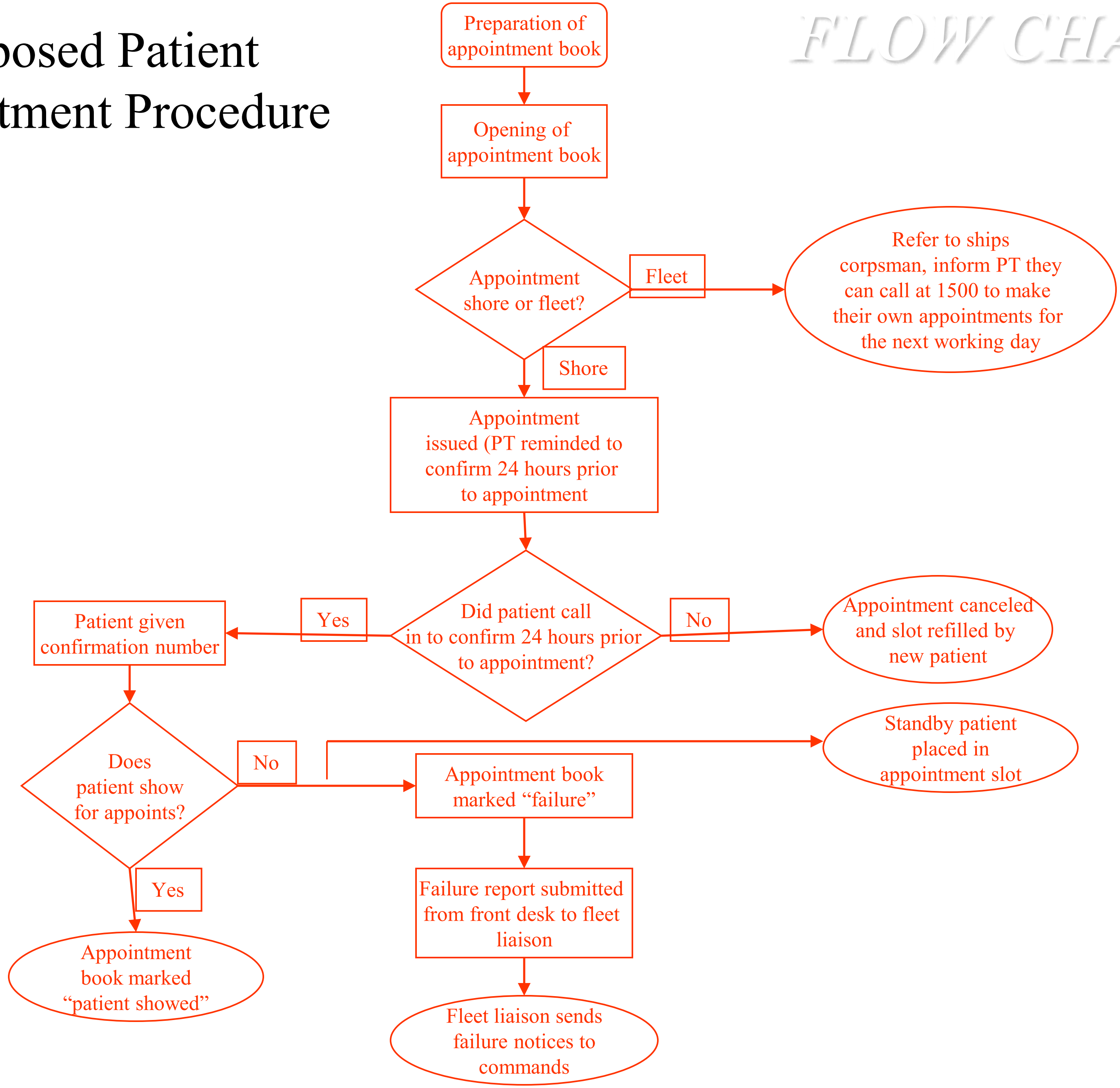
- A diagram illustrating the activities of a process
- One of Ishikawa‟s seven basic tools of quality.

Flowchart Symbols

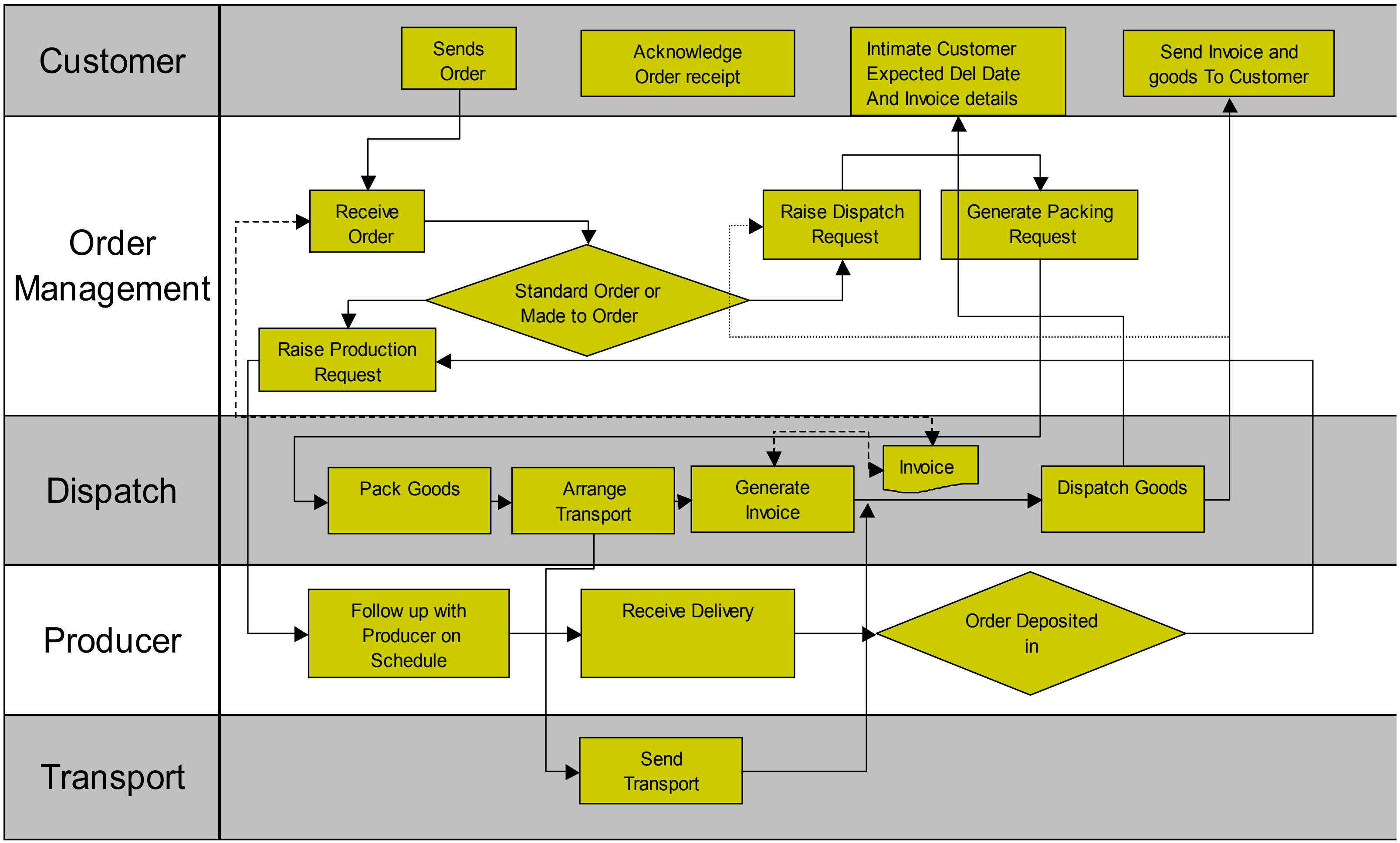
Name	Symbol	Use in flowchart
Oval		Denotes the beginning or end of a program.
Flow line		Denotes the direction of logic flow in a program.
Parallelogram		Denotes either an input operation (e.g., INPUT) or an output operation (e.g, PRINT).
Rectangle		Denotes a process to be carried out (e.g., an addition).
Diamond		Denotes a decision (or branch) to be made. The program should continue along one of two routes (e.g., IF/THEN/ELSE).

Proposed Patient Appointment Procedure

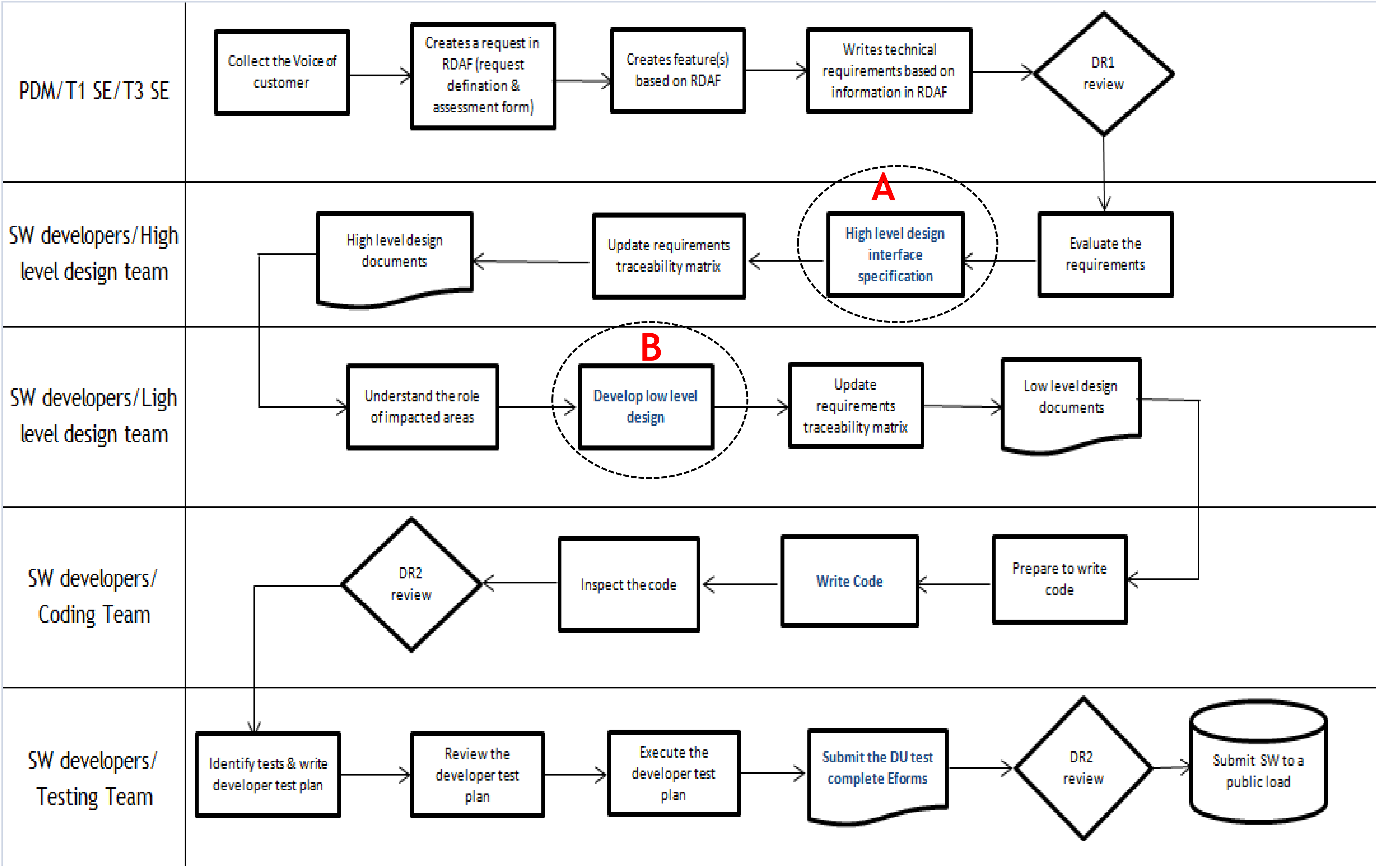
FLOW CHART



Swim Lane Flowchart Example: Fulfillment Process



Process Map



PDM/T1 SE/T3 SE
Collect the Voice of customer
Creates a request in RDAF (request defination & assessment form)
Creates feature(s) based on RDAF
Writes technical requirements based on information in RDAF
DR1 review
SW developers/High level design team
Evaluate the requirements
A
High level design interface specification
Update requirements traceability matrix
High level design documents
SW developers/Ligh level design team
Understand the role of impacted areas
B
Develop low level design
Update requirements traceability matrix
Low level design documents
SW developers/ Coding Team
Prepare to write code
Write Code
Inspect the code
DR2 review
SW developers/ Testing Team
Identify tests & write developer test plan
Review the developer test plan
Execute the developer test plan
Submit the DU test complete Eforms
DR2 review
Submit SW to a public load

VA and NVA

Every body is busy but the order is idle 90% of the time

How is it possible?

VA and NVA

Value-added step:

- Customers are willing to pay for it
- It physically change the product.
- It‟s done right the first time.

Non value-added step:

- Is not essential to produce output
- Does not add value to the output.
- Includes:
    - Defects , errors ,omissions.
    - Preparation/setup, Control/inspection
    - Inventory ,processing
    - Transporting,motion,waiting , delays.

VA and NVA

Required NVA‟s(Operational support activity)

•Business necessity (e.g. accounting)

•Employee necessity(e.g. payroll).

•Process necessity(e.g. Inspection?).

VA and NVA

Value Adds

- Entering order
- Ordering materials
- Preparing drawing
- Assembling
- Packaging
- Shipping to customer

Non Value Adds

- Waiting
- Storing
- Counting
- Inspecting
- Recording
- Testing
- Reviewing
- Copying
- Filing
- Reworking
- Tracking

Evaluation of Process Map

- Ask questions such as…
  1. Does the process work as planned?
  2. If not then what happens?
  3. Are all required items / information identified and in the process map?
- Look for opportunities to…
  1. Eliminate steps
  2. Perform steps in parallel
  3. Rearrange steps
  4. Simplify steps
  5. Expedite steps
  6. Implement less expensive operations
  7. Ensure consistent performance

WHAT DO YOU THINK ABOUT THIS PICTURE?

ROOF

WIRES

TREE

TREE

SKY

STATUE

FLOWERS

GRASS

LAMP

POLE

WINDOWS

TILES

A PICTURE IS WORTH A THOUSAND WORDS...

WHY PICTURES ARE IMPORTANT

Pictures/Displays of data stimulate hypothesis generation which is a key step in process improvement

"If I had to reduce my message to management to just a few words, I'd say it all had to do with reducing variation."

W. Edwards Deming

VARIATION: THE VOICE OF THE PROCESS

Graphical Representation of Data

- Graphs & Charts

Discrete Data Characteristics

Responses to the Satisfaction Survey	Satisfied	Not Satisfied
Top Management	15	2
Senior Management	25	3
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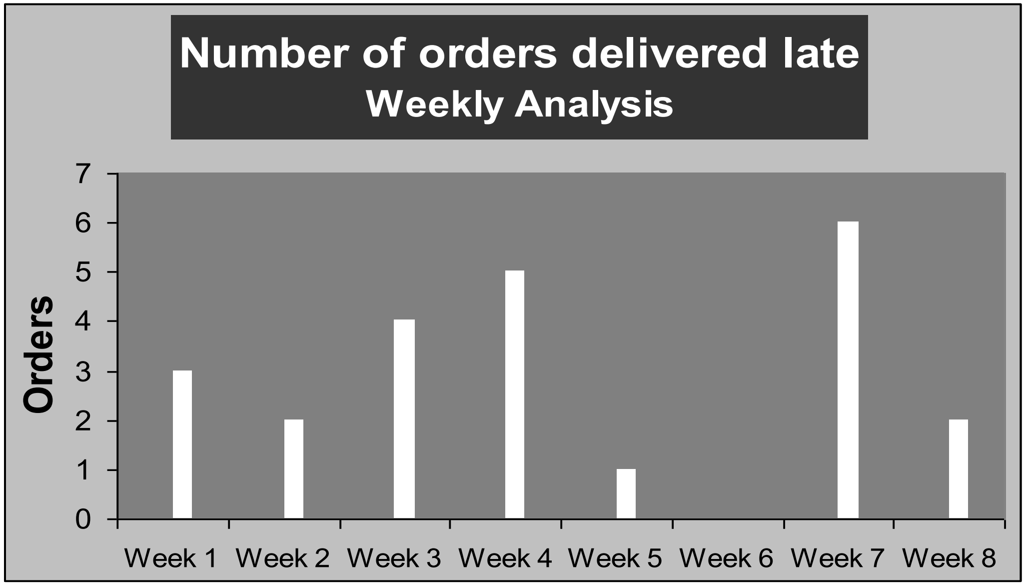
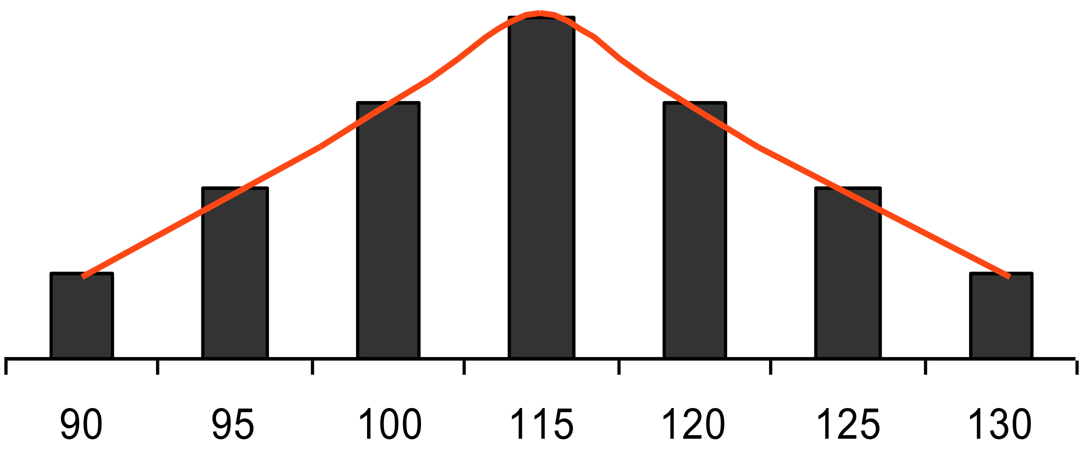


Continuous Data Characteristics

- Usually illustrated in tables & histograms / frequency polygons
  - A histogram or frequency distribution shows the number of data points in a data set that fall into each of the frequency classes
  - A frequency polygon is constructed by connecting the mid-points of each of the vertical bar in the Histogram

Test Results of a Speed Test

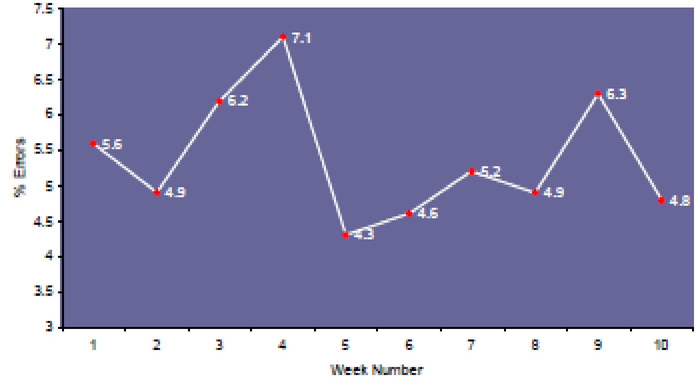
Tests	Maximum Speed in Km / Hr
1	90.0
2	95.0
3	95.0
4	100.0
5	100.0
6	100.0
7	115.0
8	115.0
9	115.0
10	115.0
11	120.0
12	120.0
13	120.0
14	125.0
15	125.0
16	130.0



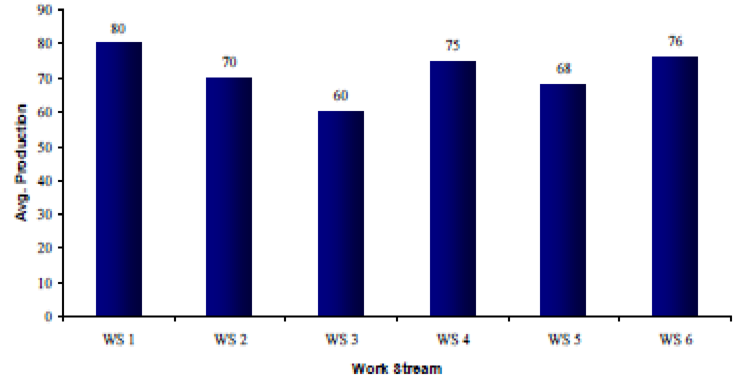
Purpose of Graphs and Charts

- Graphs and charts are pictorial representation of the data, making it easy to spot trends and comparisons among different groups of data.
- The more common types of graphs and charts are Line graphs, Bar charts and Pie charts.
- To present the numerical data in an easy-to-plot visual form.

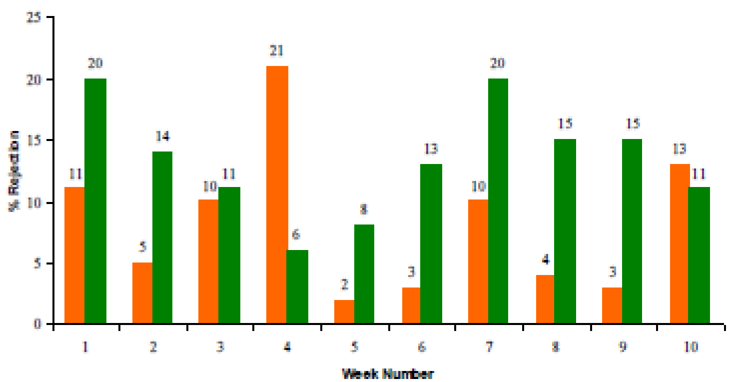
Weekly % Errors



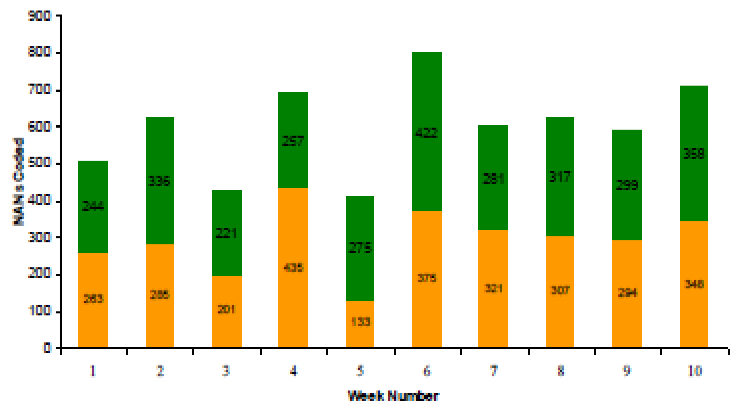
Work Stream based Avg Production



Weekly Reject comparison for WS 1 & 2



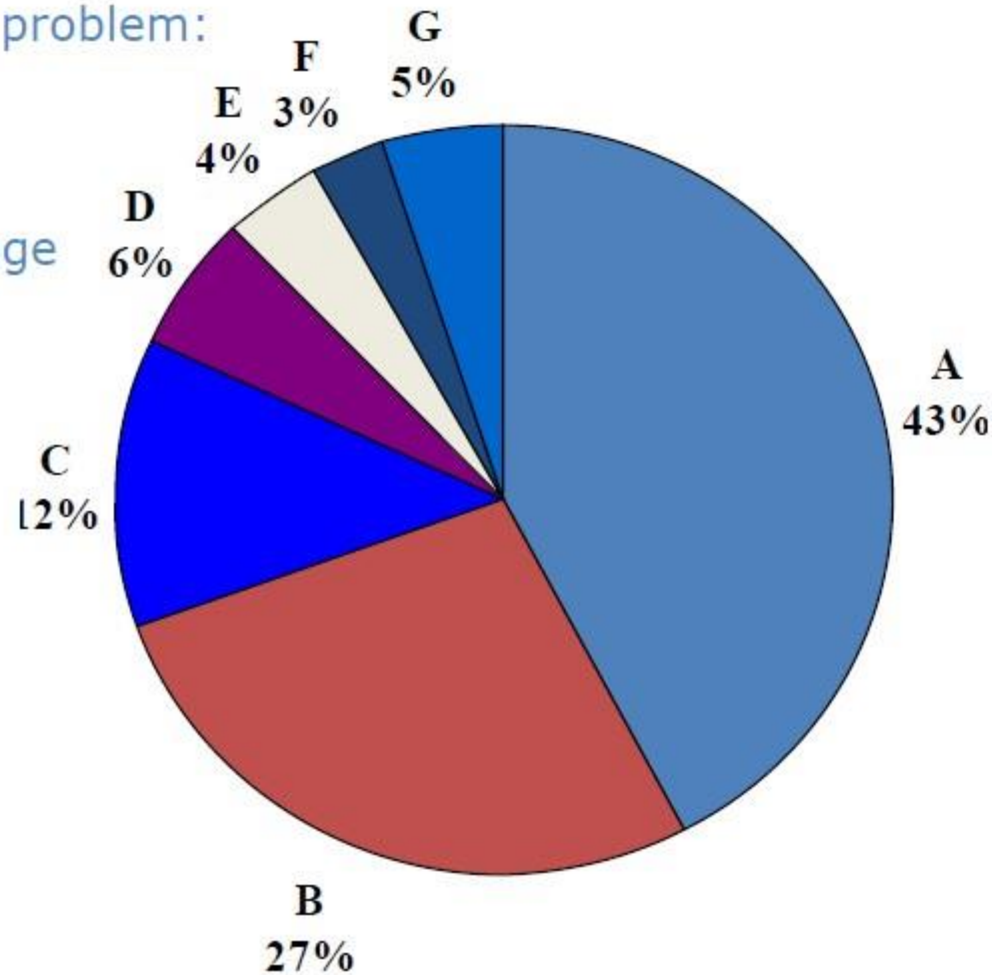
Comparison of WS 1 & 2 production



What do you infer on this ?

Watch maker analyzing problem:

- A - Glass Broken
- B – Movement Stoppage
- C - Mvt. Trouble
- D - Defective Dial
- E - Regulation
- F - Stem Loose
- G - Others



FREQUENCY DISTRIBUTION

AND

HISTOGRAM

WHAT DO THESE NUMBERS MEAN TO YOU ?

2.87, 2.85, 2.88, 2.85, 2.86, 2.85, 2.81, 2.82,
2.83, 2.85, 2.84, 2.84, 2.85, 2.86, 2.85, 2.84,
2.85, 2.85, 2.87, 2.81, 2.85, 2.82, 2.83, 2.85,
2.85, 2.86, 2.85, 2.86, 2.89, 2.85, 2.84, 2.84,
2.85, 2.85, 2.83, 2.82, 2.86, 2.83, 2.85, 2.86,
2.85, 2.84, 2.84, 2.87, 2.85, 2.86, 2.85, 2.84,

2.90, 2.88

PROBABLY NOTHING MUCH !

NOW DO THE FOLLOWING

- ☞ **Find the minimum value.**
- ☞ **Find the maximum value.**
- ☞ **Arrange all values between minimum & maximum value in ascending order.**
- ☞ **For each number, in the table make a mark, after reading each number from the given jumble of numbers.**

YOUR TABLE LOOKS SOMETHING LIKE THIS?

Value	Tally	Frequency
2.80	-	0
2.81	II	2
2.82	III	3
2.83	IIII	4
2.84	IIIIIIII	8
2.85	IIIIIIIIIIIIIIIIIII	19
2.86	IIIIIII	7
2.87	III	3
2.88	II	2
2.89	I	1
2.90	I	1

THIS DATA NOW TELLS YOU...

- ☞ 2.85 occurs with a maximum frequency of 38 %.
- ☞ Approximately 82% of the values lie between 2.83 and 2.87.

THIS TABLE THAT GIVES YOU THIS DISTRIBUTION IS CALLED :

FREQUENCY DISTRIBUTION.

NOW DO THIS

- **For the same data, divide the range (i.e... 2.9- 2.80 = 0.10) in equal no.of parts (say 5).**
- **Hence each part will be equal to 0.02.**
- **The table now will have values: 2.8-2.82, 2.82-2.84, 2.84-2.86, 2.86-2.88, 2.88-2.9**

NOW PLOT THE DISTRIBUTION AGAIN FOR THE TABLE. IT LOOKS LIKE THIS...

Class	Tally	Frequency
2.80-2.82	IIIII	5
2.82-2.84	IIIIIIIIIIII	12
2.84-2.86	IIIIIIIIIIIIIIIIIIIIIIIIII	26
2.86-2.88	IIIII	5
2.88-2.90	II	2

The spread of each range is (e.g.. : 2.82 - 2.80 = 0.2) is called **Class Interval.**

THIS TELLS YOU THAT

- **52% of values lie in 2.84 - 2.86 range.**
- **What is the distribution in a given range.**
- **It is helpful when you have a large number of values .**

KEY MANAGEMENT QUESTIONS FOR UNDERSTANDING VARIATION

❖ What does the process variation look like?

❖ Is the process stable (free of special cause variation)?

❖ What is the level of process capability (meeting customer expectations)?

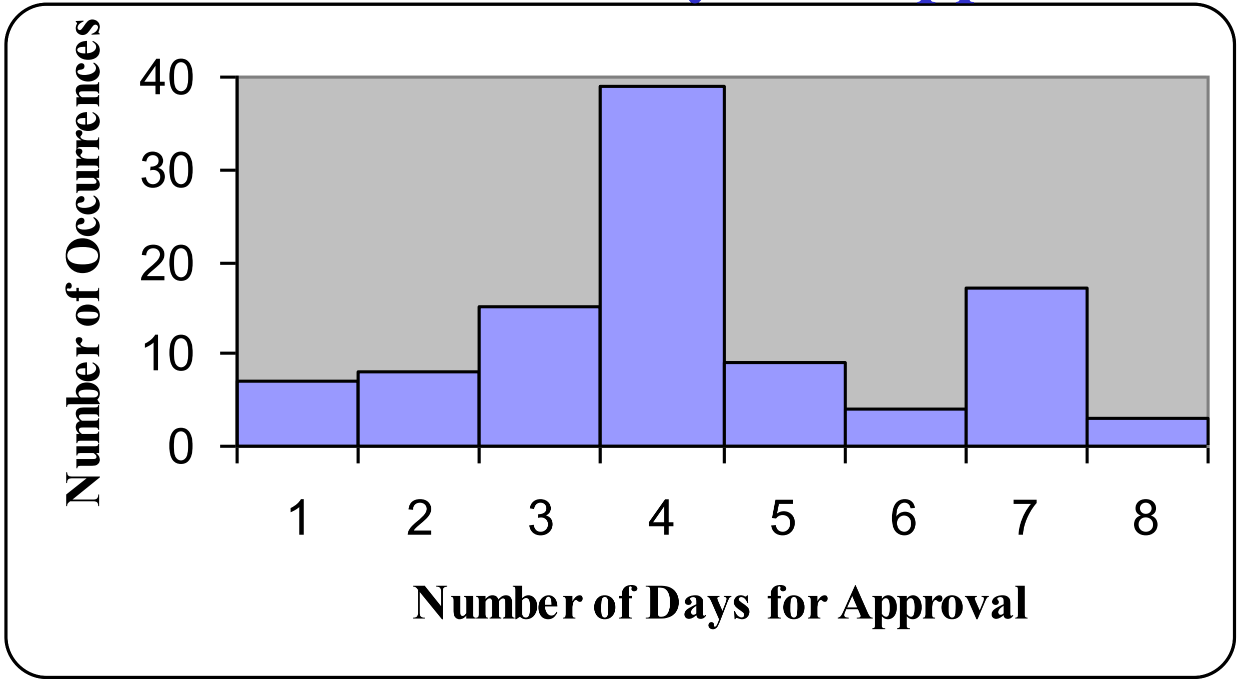
HISTOGRAMS: VARIATION FOR A PERIOD OF TIME

DEFINITION

A Histogram shows the shape, or distribution, of the data by displaying how often different values occur.

EXAMPLE

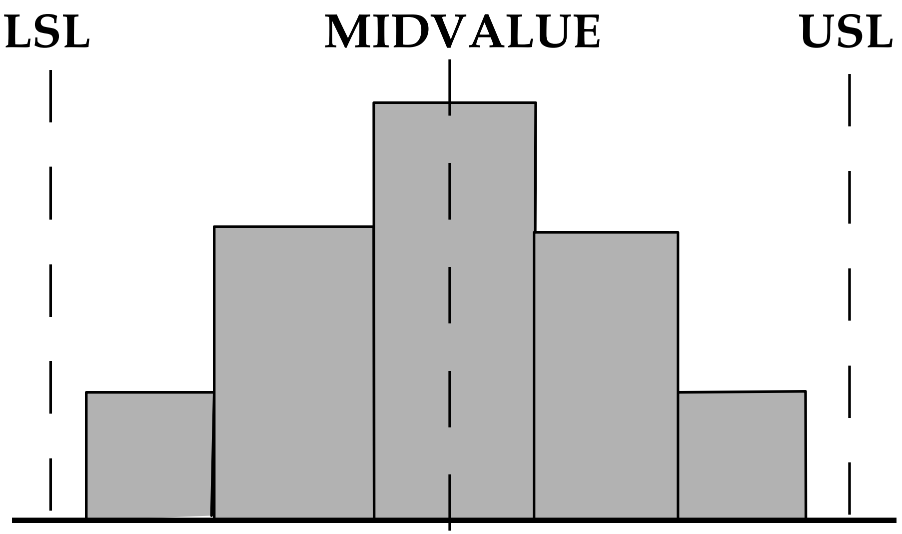
"Number of Days for Approval"



HISTOGRAM

- A Histogram gives you the Frequency distribution pictorially.
- The concept of X - Y axis and origin need not be followed once you gain proficiency in drawing histograms.
- The specified limits can be marked on histograms to show the behavior of variation versus the actual required values.

LOOK AT THIS HISTOGRAM



- Has its mid-value equidistant from both the end values
- Is symmetric about the mid value?

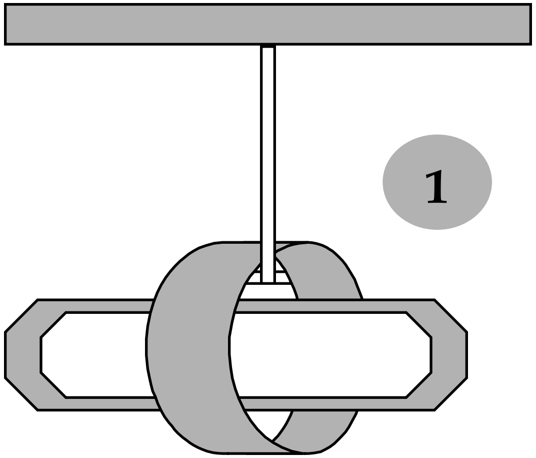
This is the most likely histogram for a **Process Under Control**

MEASURES OF

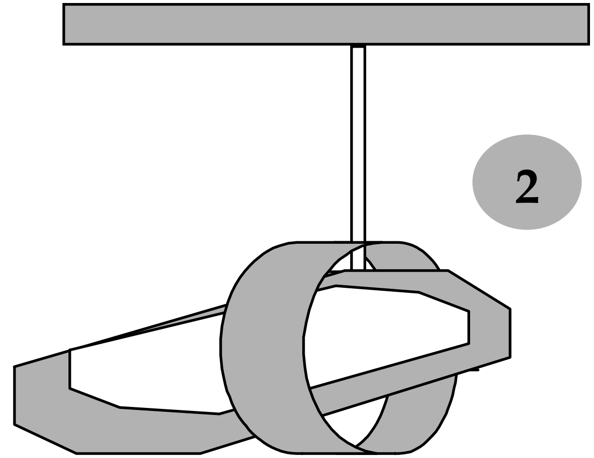
CENTRAL TENDENCY

AND

DISPERSION



This Suspended Pipe Is Horizontal



The Same Pipe Has Now Tilted

WHY ?

The rope is tied at the center of gravity.

The rope is tied away from the center of gravity.

Center of gravity is the point where the entire mass of the body is supposed to be concentrated.

Thus center of gravity is a measure of central tendency of a body.

WHAT IS THE MEASURE OF CENTRAL TENDENCY OF A SET OF NUMBERS?

- There are three ways in which ***Central Tendency*** of Numbers can be measured.
- These are the 3 M's
    - **MEAN**
    - **MEDIAN**
    - **MODE**

MEAN

Mean or Average is normally signified by

$$\text{Mean} = \frac{\text{Summation of all the values}}{\text{Number of values}}$$

Mathematically it can be represented as :

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Let us now find the mean of the values of our earlier data.

$$\overline{X} = \frac{2.87 + 2.85 + 2.88 + ... + 2.88}{50} = 2.849$$

MEDIAN

- This is the value which has equal number of values above it and below it, when arranged in ascending order.

- Mathematically :

$$\mathbf{Median} = \begin{cases} \dfrac{\left(\dfrac{n}{2}\right)^{th} \text{Value} + \left(\dfrac{n}{2}+1\right)^{th} \text{Value}}{2} & ; \text{ when } n \text{ is even} \\[2em] \left(\dfrac{n+1}{2}\right)^{th} \text{Value} & ; \text{ when } n \text{ is odd} \end{cases}$$

Referring to our earlier example and arranging in ascending order we get,

2.81, 2.81, 2.82, 2.82, 2.82, 2.83,…..,2.88, 2.88, 2.89, 2.90

Number of values (n) = 50. **This is Even.**

$$\textbf{Hence, Median} = \frac{\left(\frac{50}{2}\right)^{th}\ \text{Value} + \left(\frac{50}{2}+1\right)^{th}\ \text{Value}}{2}$$

$$= \frac{25^{th}\ \text{Value} + 26^{th}\ \text{Value}}{2} = \frac{2.85 + 2.85}{2} = 2.85$$

THIS IS THE MEDIAN FOR OUR EXAMPLE

MODE

- *This is the value which occurs with the highest frequency.*
- **In our case it is *2.85* which occurred *19 times.***

- **We have thus calculated, The Mean, Median and Mode for a given data set**
- **The Mean, Median and Mode are equal for a symmetric unimodal distribution.**
- **They are not equal if distribution is not symmetric.**

MEASURES OF DISPERSION

- *The extent of the spread of the values from the mean value* ***is called Dispersion.***

- The measures of Dispersions are
  - Range (R)
  - Standard Deviation (s)
  - Variance (s^2)

- **Standard deviation is the most commonly used measure of dispersion.**

STANDARD DEVIATION

OF POPULATION:

If $X_1, X_2, \ldots\ldots, X_n$ are sample values and μ is their poulation mean.

$$\sigma = \sqrt{\frac{(X_1 - \mu)^2 + (X_2 - \mu)^2 + \ldots\ldots + (X_n - \mu)^2}{n}} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \mu)^2}{n}}$$

OF SAMPLE :

If $X_1, X_2, \ldots\ldots, X_n$ are sample values and $\overline{X}$ is their sample mean.

$$s = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots\ldots + (X_n - \overline{X})^2}{(n-1)}} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{(n-1)}}$$

Degrees of freedom

DEGREES OF FREEDOM

- If you are told to decide 5 nos such that the average of these nos is 10 you will realize that you are free to select only 4 of the 5 nos and the 5th will necessarily be fixed.
- e.g. 10, 14, 3 & 17 are the four nos that you have selected. The 5th no. necessarily will have to be 6.
- ***The no. of values you are free to select is known as the degrees of freedom (d.f.).***
- In this case the degree of freedom is 4.
- In general ***d.f. = n-r*** ; where n is the no. of readings & r is the no.of statistical parameters to be found.

ALTERNATIVELY

$$s = \sqrt{\frac{(X_1^2 + X_2^2 + \ldots.. + X_n^2) - n\overline{X}^2}{(n-1)}} = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 - n\overline{X}^2}{(n-1)}}$$

$$= \sqrt{\frac{(2.87^2 + 2.85^2 + \ldots.. + 2.88^2) - 50(2.849)^2}{(50-1)}} = 0.0181$$

This is also known as

Root Mean Square Deviation (R.M.S.)

Range, R = **Largest Observation - Smallest Observation**

$= X_{max} - X_{min}$

Variance (s^2) is the Square of Standard Deviation.

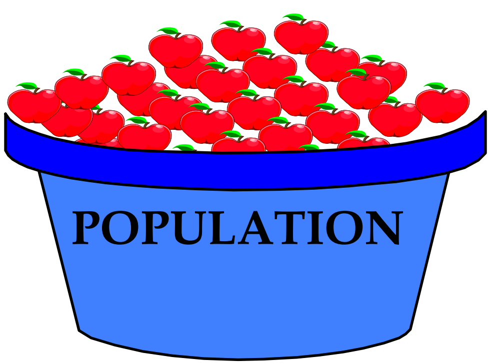
Data Collection Plan

Measure	Measure Type (Y, X)	Data Type	Operational Definition	Who Collects Data	Data Source	Frequency o[f] Data Collection
AHT	Y	Continuous	Time from agent picking up the call to call closure	Greenbelt	Switch / Avaya	100%
Login Efficiency	X	Continuous	Ratio of Login hours to Actual Working Hours	Team Member Name	XYZ	100%
Hang-up Reasons	X	Discrete	Customers Reasons for Hanging up	Team Member Name	ABC	One per hou[r] selected Randomly

Microsoft Excel Worksheet

POPULATION AND SAMPLE

- The entire set of items is called the *Population*.
- The small number of items taken from the population to make a judgment of the population is called a *Sample*.
- The numbers of samples taken to make this judgment is called *Sample size.*



SAMPLE OF SIZE THREE

WHAT IS SAMPLING AND WHY DO IT?

- **Sampling is**
  - **Collecting a portion of *all* the data.**
  - **Using that portion to draw conclusions (make inferences).**
- **Why sample? Because looking at *all* the data may be**
  - **Too expensive.**
  - **Too time-consuming.**
  - **Destructive (e.g., taste tests).**

- **Sound conclusions can often be drawn from a relatively small amount of data.**

Sampling Methods

Four methods of sampling:

•Random sampling

•Stratified sampling

•Clustered sampling

•Systematic sampling

Random Sampling

All items in the population have an equal chance of being chosen in the sample

Example: A customer satisfaction survey team picking the customers to be contacted at random

How to do random sampling

Generate random numbers from computer / printed tables

Write each unit on a piece of paper & deposit the slips in a box

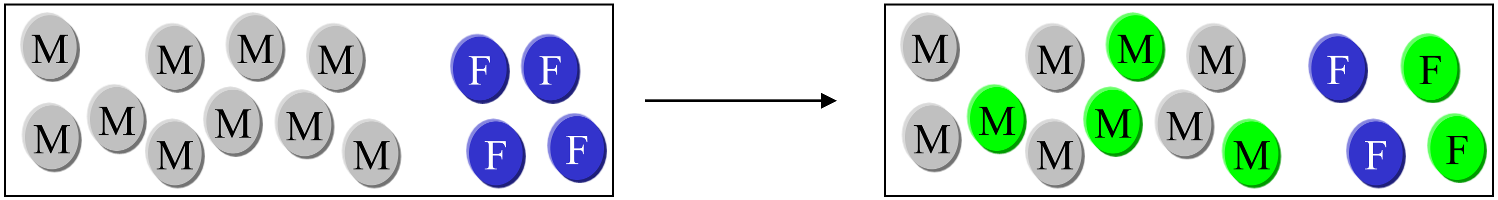
Stratified Sampling

When to use Stratified sampling?

When the population consists of mixture of more than one strata, each forming a homogeneous group, Stratified sampling can assure that sample represents the population adequately.

Like random samples, stratified random samples are used in population sampling situations, when reviewing historical or batch data.

This method may be the only way to accurately capture performance for different segments of the process.



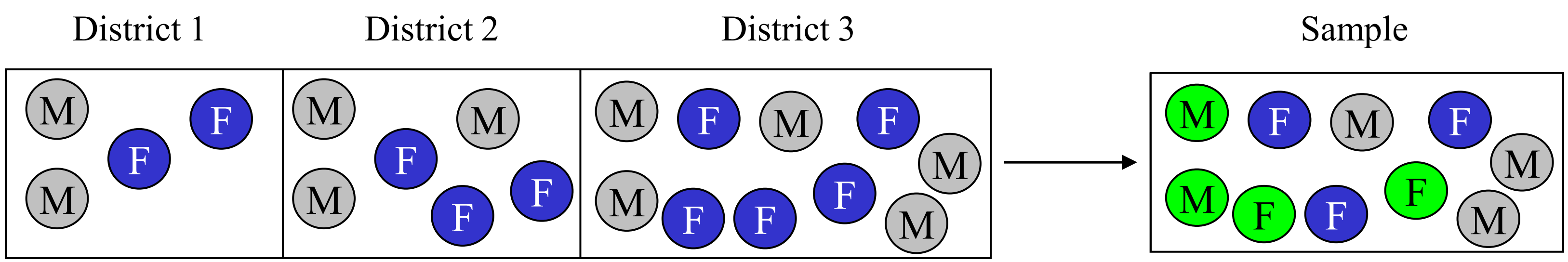
A sample of size 6 - *4 males & 2 females*

Clustered Sampling

When the population consists of clusters, each having large variation within the cluster, but clusters are essentially similar to each other.

We select a random sample of the clusters and assume that these clusters represent the population as a whole

This situation is quite opposite to the condition for stratified sampling

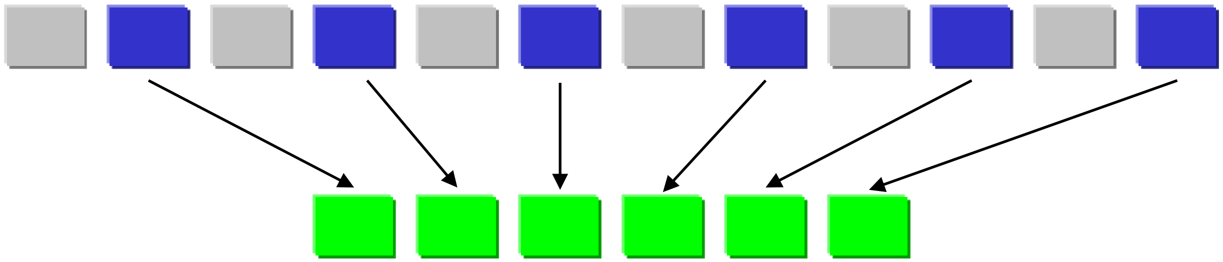


Systematic Sampling

•Systematic sampling is the selection of samples from a population according to a set schedule or plan

•Systematic sampling is typically used in process sampling situations when data is collected "real time" during process operation.

•A frequency for sampling must be selected.



Every second item is being systematically picked

Sampling Bias

Regardless of the situation, a sample must be “representative” of the population. For practical purposes a sample is representative if it accurately represents the target population. Consideration that may hinder collection of a representative sample include:

- ***The cost and ease of obtaining samples***
- ***Time constraints***
- ***Unknown characteristics of the population***

Samples that are not representative of a target population are called biased samples. Often, the biases are not recognized until the collected data has been analyzed.

Sample Size Calculation

Sample size (n) depends on three things:

- Level of confidence required for the result, "How confident we are that the result represents the true population"
  - Level of confidence increases as sample size increases.
- Precision or accuracy (Δ) required in the result, "The error bars or uncertainty in my result"
  - Precision increases as sample size increases
- Variation in the process
  - Higher the variation, high is the sample size for a confidence level.

Sample Size Calculation

Continuous Data

$$\textbf{Sample Size n} = \left\{ (1.96\ \sigma) / \blacktriangle \right\}^{2}$$

- σ (Standard deviation) of the population tells us how much variation is there in the process
- How to get Standard Deviation.
- ▲ is the Precision or accuracy of the process.
- How to get value for ▲.

How To Estimate σ

How to Estimate σ

- Collect a small sample (at least 30) of subgroup 3 each, and calculate range for each subgroup. R =(Max Value – Min Value). Then Calculate Average Range (R-bar)

$$\sigma = \text{R-bar} / d2$$

- Collect individual Readings (X). Calculate Average (X bar). For each value Subtract „X‟ from „X bar‟ (X-X bar). Square all (X-X bar) and Add . Use Formula below.

$$\sigma = \sqrt{\Sigma(\text{X-X bar})^2 / N}$$

How to Determine Δ

- Use business knowledge
- Take the Δ from the sample size you can afford; for example, with 95% confidence

$$\Delta = \left(\frac{1.96\,(\sigma)}{\sqrt{n}} \right) \text{if } n = 15 \text{ and } s = 3$$

$$\Delta = \left(\frac{1.96 \text{ x } 3}{3.87} \right) = 1.51$$

- Consider the minimum resolution of measurement equipment. For example, don‟t set Δ to minutes if you can measure only hours.

Sample Size Example

Continuous Data Example:

Calculate sample size for a population having Standard Deviation of 2.5 and at a precision level of 0.5 and at confidence level of 95%.

$$\text{Sample Size } n = \left\{ (1.96\ \sigma) / \Delta \right\}^2$$

$$= \{1.96 * 2.5 / 0.5\}^2 = \{9.8\}^2$$

$$= 96.04$$

Sample Size Calculation

Discrete Data

$$\textbf{Sample Size n} = \left\{ (1.96) / \Delta \right\}^2 p(1-p)$$

- P is proportion defective (Number of units defective / total units)

Sample Size calculator

https://www.surveymonkey.com/mp/sample-size-calculator/

Estimate Population Parameters from Sample Statistics

Estimates

- Estimates are formed even in general life
- It is about making inferences about the population from a given sample
- Types of estimates
  - Point estimate - a single number for the estimated population parameter
  - Interval estimate - range of values for the estimated population parameter (Confidence Interval)
    - Interval estimates also indicate the probability of true population parameter being inside the confidence interval that is known as <u>confidence level</u>

Point Estimates

- Sample mean „$\bar{Y}$“ is the point estimate of the population mean „μ“
- Sample standard deviation „s“ is the point estimate of the population standard deviation „σ“

Sample Mean „$\bar{Y}$“

$$\frac{Y_1 + Y_2 + Y_3 + \ldots + Y_n}{n}$$

Sample Variance „s^2“

$$\frac{(Y_1 - \bar{Y})^2 + (Y_2 - \bar{Y})^2 + \ldots + (Y_n - \bar{Y})^2}{(n-1)}$$

Sample Standard Deviation „s“

$$s^2$$

Confidence Intervals

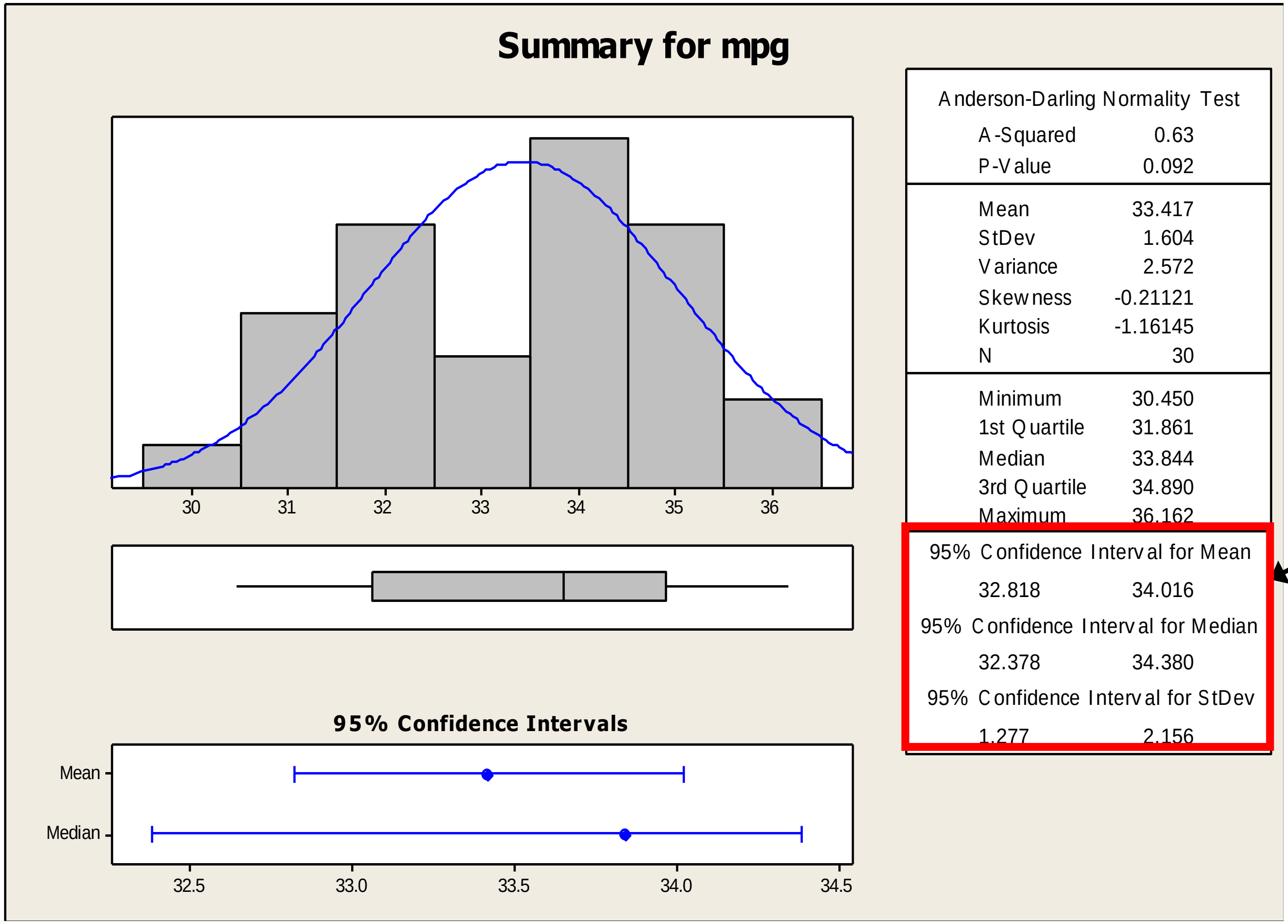
- When we calculate statistics such as the mean for a data set, we are making an estimate of the true value since we are dealing with a sample of the population
- Based on our estimate from the sample we draw inferences about the population
- Making decisions based on point estimates can be very risky:
  - The true value might vary considerably from the point estimate
  - We should ask: what is the accuracy of estimate?
- Decisions should always be based on confidence intervals not point estimates

Confidence Intervals in words

All confidence intervals are constructed around:

$$\text{point estimate} \pm \frac{(\text{confidencescaling factor} \times \text{measure of variation})}{\text{sample size}}$$

- As sample size increases
  C.I. narrows
- As measure of variation increases
  C.I. widens
- As confidence increases
  C.I. widens



Inferential Statistics

Confidence Levels

Confidence Level		α Risk	
90%	9 times out of 10 the true value will lie within the confidence interval	0.1	Only 1 in 10 times will the true value lie outside the confidence interval
95%	19 times out of 20 the true value will lie within the confidence interval	0.05	Only 1 in 20 times will the true value lie outside the confidence interval
99%	99 times out of a 100 the true value will lie within the confidence interval	0.01	Only 1 in 100 times will the true value lie outside the confidence interval
99.9%	999 times out of 1000 the true value will lie within the confidence interval	0.001	Only 1 in 1000 times will the true value lie outside the confidence interval

Process Sigma Calculation

- **Discrete Data**
  - Follow the Defects Per Million Opportunity (DPMO) method
  - Have the yield calculation

- **For Continuous Data**
  - Calculate the Z value
  - Refer the Z distribution table and look up the sigma value

Process Sigma – Discrete Data

Concept	**Definition**
Critical-To-Quality Characteristics (CTQ)	Customer performance requirements of a product or service
Unit	The item produced or processed
Defect	Any event that does not meet the specifications of a CTQ
Defect Opportunity	Any event which can be measured that provides a **chance** of not meeting a customer requirement
Defective	A unit with one or more defects

Process Sigma – Discrete Data – DPMO Method

1. Number of Units processed N = __________
2. Number of Defect Opportunities Per Unit O = __________
3. Total number of Defects made D = __________

   (include defects made and later fixed)
4. Solve for Defects Per Opportunity =
5. Convert DPO to DPMO

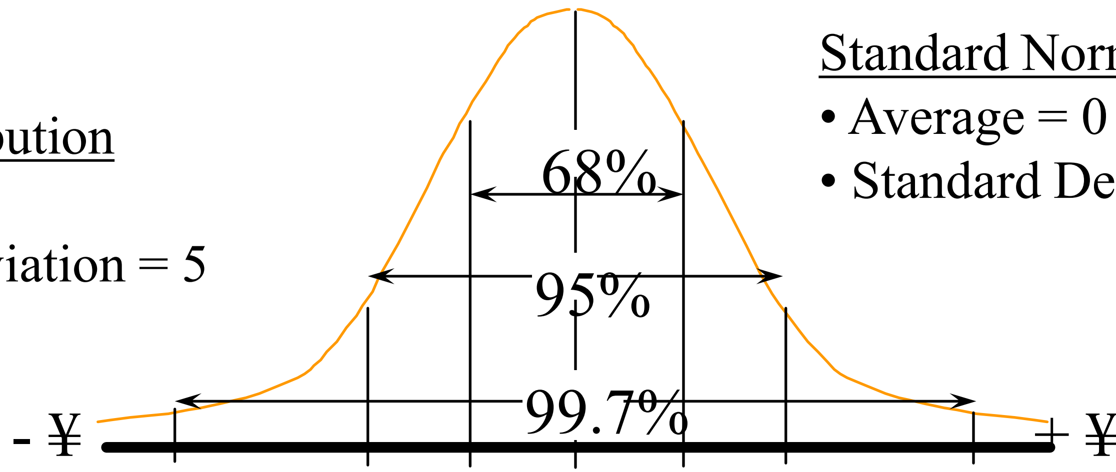
$$DPO = \frac{D}{N \bullet O}$$

$$DPMO = DPO \bullet 1{,}000{,}000 = \_\_\_\_\_\_\_\_\_\_ \bullet 1{,}000{,}000 = \_\_\_\_\_\_\_\_\_\_$$

6. Look up Process Sigma in
   Abridged Process Sigma Conversion Table Sigma = __________

A Normal Distribution Curve

Normal Distribution
- Average = 25
- Standard Deviation = 5



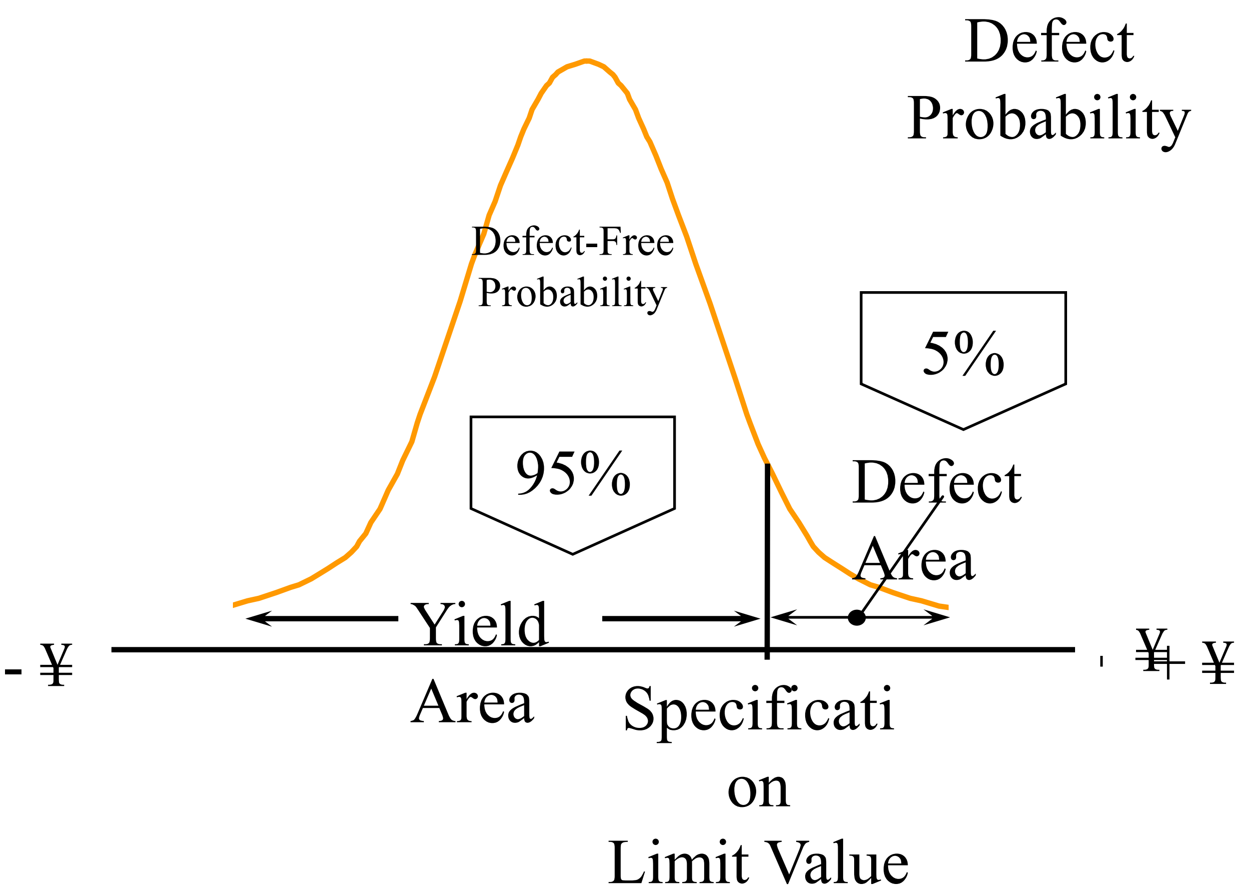
Standard Normal Distribution
- Average = 0
- Standard Deviation = 1

VALUES (time): 10 15 20 25 30 35 40

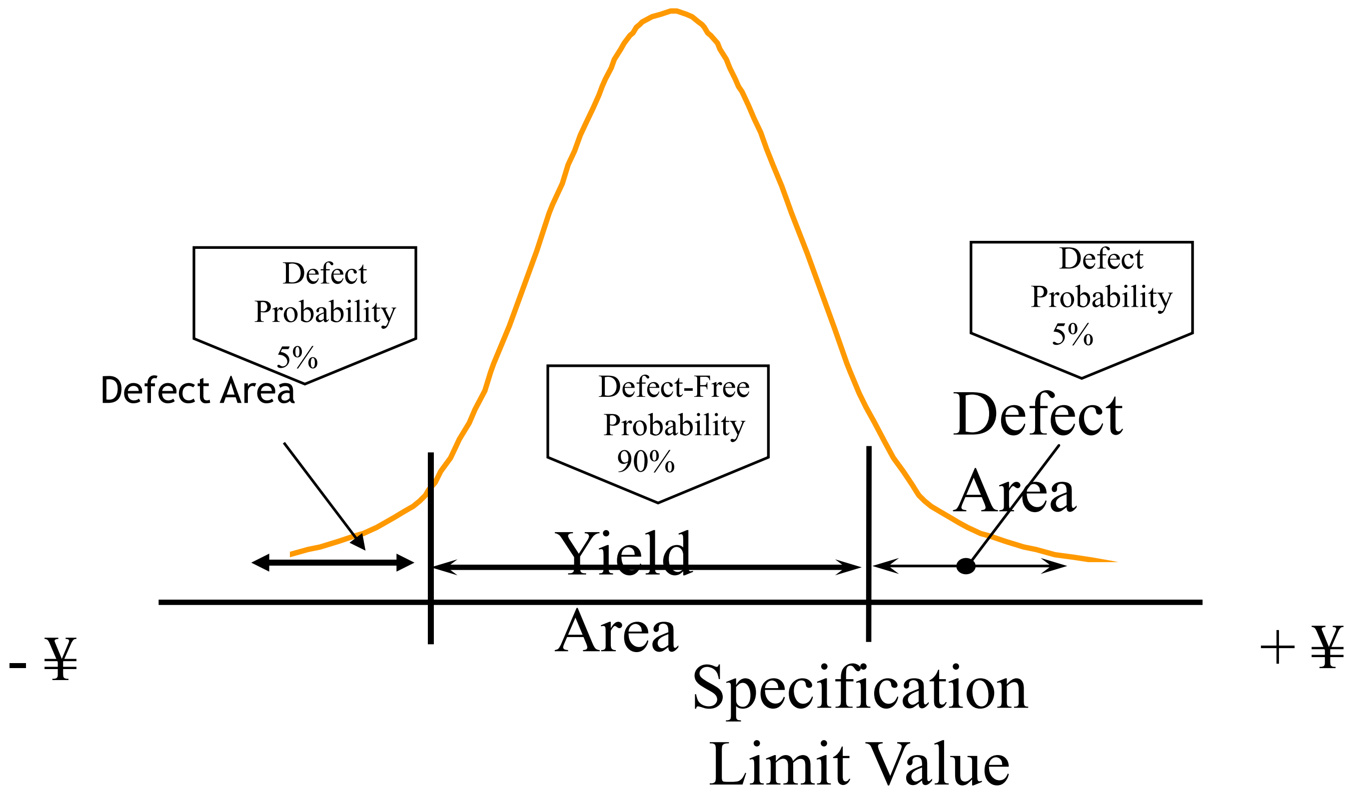
Z-VALUES s : -3 -2 -1 0 1 2 3

- Z is a Unit of Measure that is Equivalent to the Number of Standard Deviations a Value is Away From the Mean Value

Yield and Defect Probabilities For One Tailed Specification



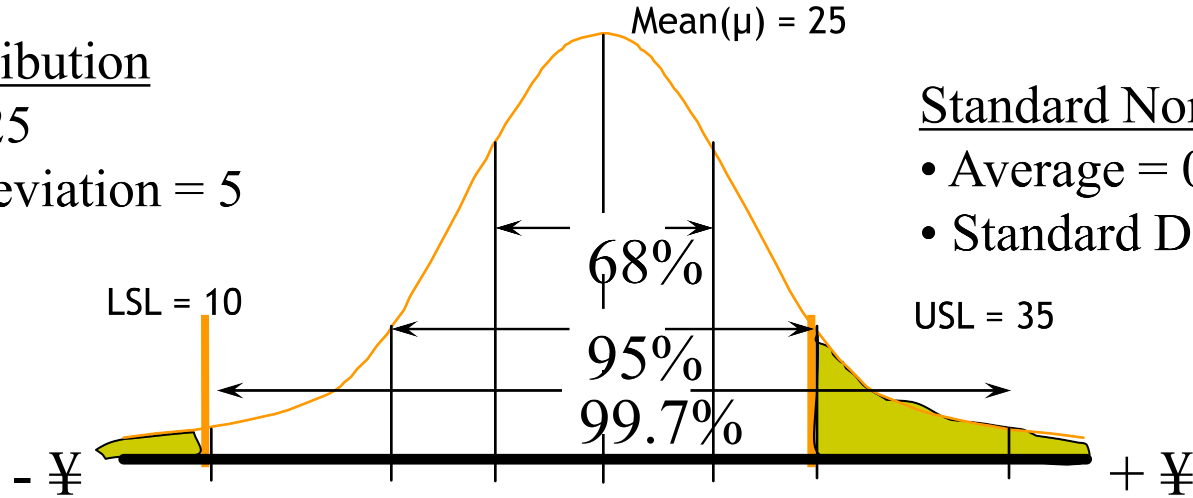
Yield and Defect Probabilities For Two Tailed Specification



Calculating the Z Value

<u>Normal Distribution</u>
- Average = 25
- Standard Deviation = 5

<u>Standard Normal Distribution</u>
- Average = 0
- Standard Deviation = 1



VALUES (time): 10 15 20 25 30 35 40

Z-VALUES s : -3 -2 -1 0 1 2 3

$$Z_{LSL} = \frac{LSL - \mu}{\sigma} \qquad Z_{USL} = \frac{USL - \mu}{\sigma}$$

$$Z_{LSL} = \frac{10 - 25}{5} = -3 \qquad Z_{USL} = \frac{35 - 25}{5} = 2$$

From Appendix 1:

Total area covered upto Z_{USL} = 0.977249938

Total area beyond Z_{LSL} = 1 - 0.998650033 = 0.0707

Intercepted area between Z_{total} = 0.977249938- 0.0707

= 0.90654

Yield = 0.90 = 90%

Sigma = 2.8

DPMO to Z Conversion Table

DPMO	Sigma Multiple
> = 500000	1.50
450000	1.63
400000	1.75
350000	1.89
300000	2.02
250000	2.17
200000	2.34
150000	2.54
100000	2.78
50000	3.14
40000	3.25
35000	3.31
30000	3.38
25000	3.46
20000	3.55
15000	3.67
12000	3.76

DPMO	Sigma Multiple
10000	3.83
9000	3.87
8000	3.91
5000	4.08
3500	4.20
1500	4.47
1000	4.59
500	4.79
483	4.80
233	5.00
108	5.20
48	5.40
21	5.60
8	5.82
5	5.91
3.4	6.01
0.4	6.57

Z to DPMO Conversion Table

Sigma Multiple	DPMO
1.6	460172
1.7	420740
1.8	382089
1.9	344578
2	308538
2.1	274253
2.2	241964
2.3	211855
2.4	184060
2.5	158655
2.6	135666
2.7	115070
2.8	96801
2.9	80757
3	66807
3.1	54799
3.2	44565

Sigma Multiple	DPMO
3.3	35930
3.4	28716
3.5	22750
3.6	17864
3.7	13903
3.8	10724
3.9	8198
4	6210
4.1	4661
4.2	3467
4.5	1350
5	233
5.2	108
5.5	32
6	3
6.1	2
6.2	1

Minitab Introduction

- MINITAB is the statistical software package of choice in every major Six Sigma initiative around the world

- MINITAB combines a comprehensive array of statistical methods, graphics tools, and project organization features in a user-friendly package that puts quality solutions within anybody‟s reach.

- Applicability
  - Control charts: To check whether the process is in control
  - Capability analysis: To check whether the process is operating within the specification limits
  - Design of Experiment: To further improve the process

Minitab Introduction

Simple to Use

- Minitab's widespread use as a statistics instruction aid

- Minitab allows professionals and statistics students alike to use effectively.

Graphics

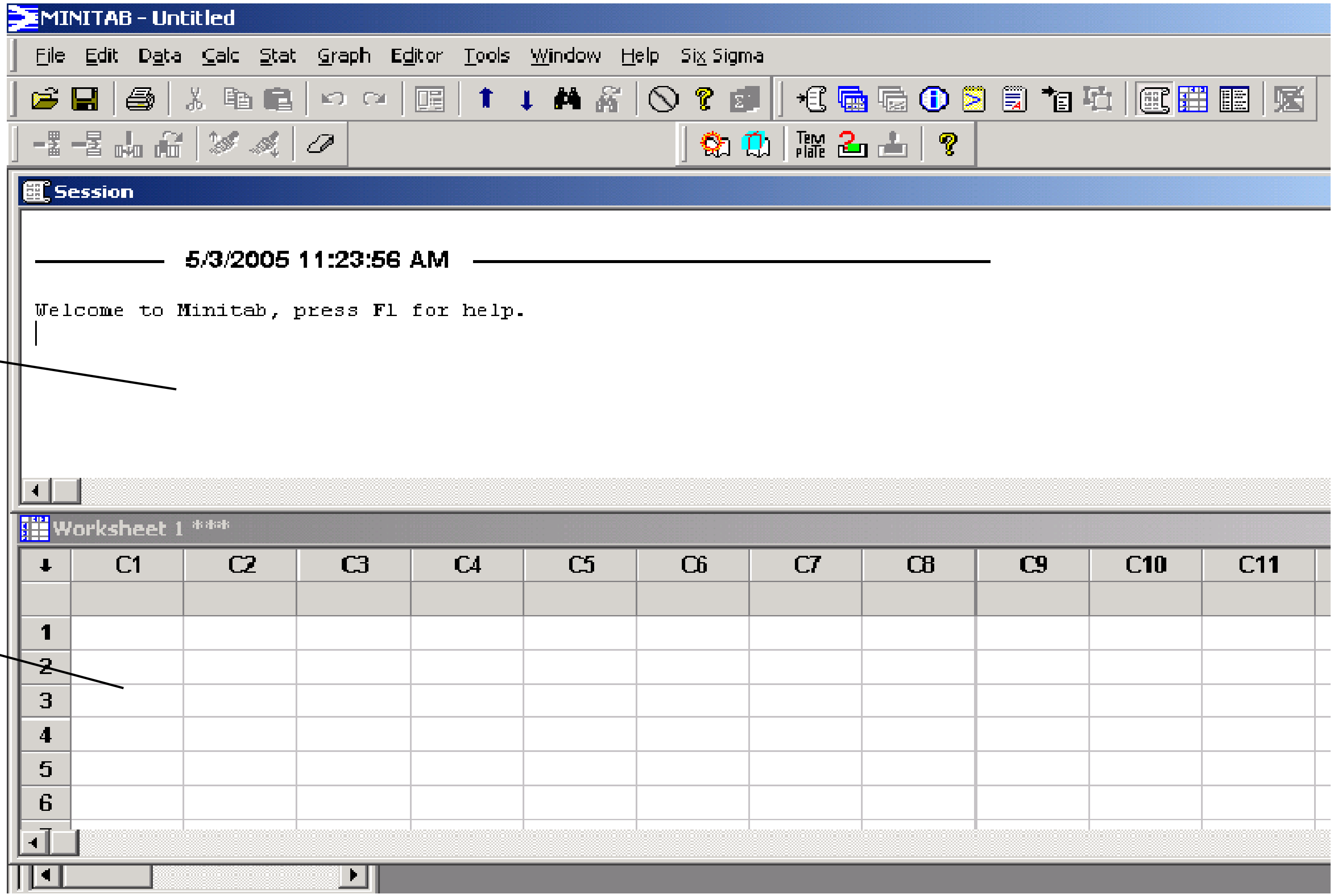
- Minitab's immense collection of dynamic graphs and graphics tools are very powerful.

Powerful Statistical Tools

- Minitab is the right tool for the job when it comes to data analysis and making quality improvements.

Minitab introduction and basics

Minitab Front Screen



This is session window

This is Data window

Minitab introduction and basics

- Session Window : All statistical analysis are saved here.

- Data Window : Worksheet data is displayed in the Data window. Here we can add delete or modify data. Data can be extracted from excel, can copy & paste the data in Data window.

- Minitab accepts 3 types of data: Numeric, text and date/time

- Each worksheet file contains single worksheet.

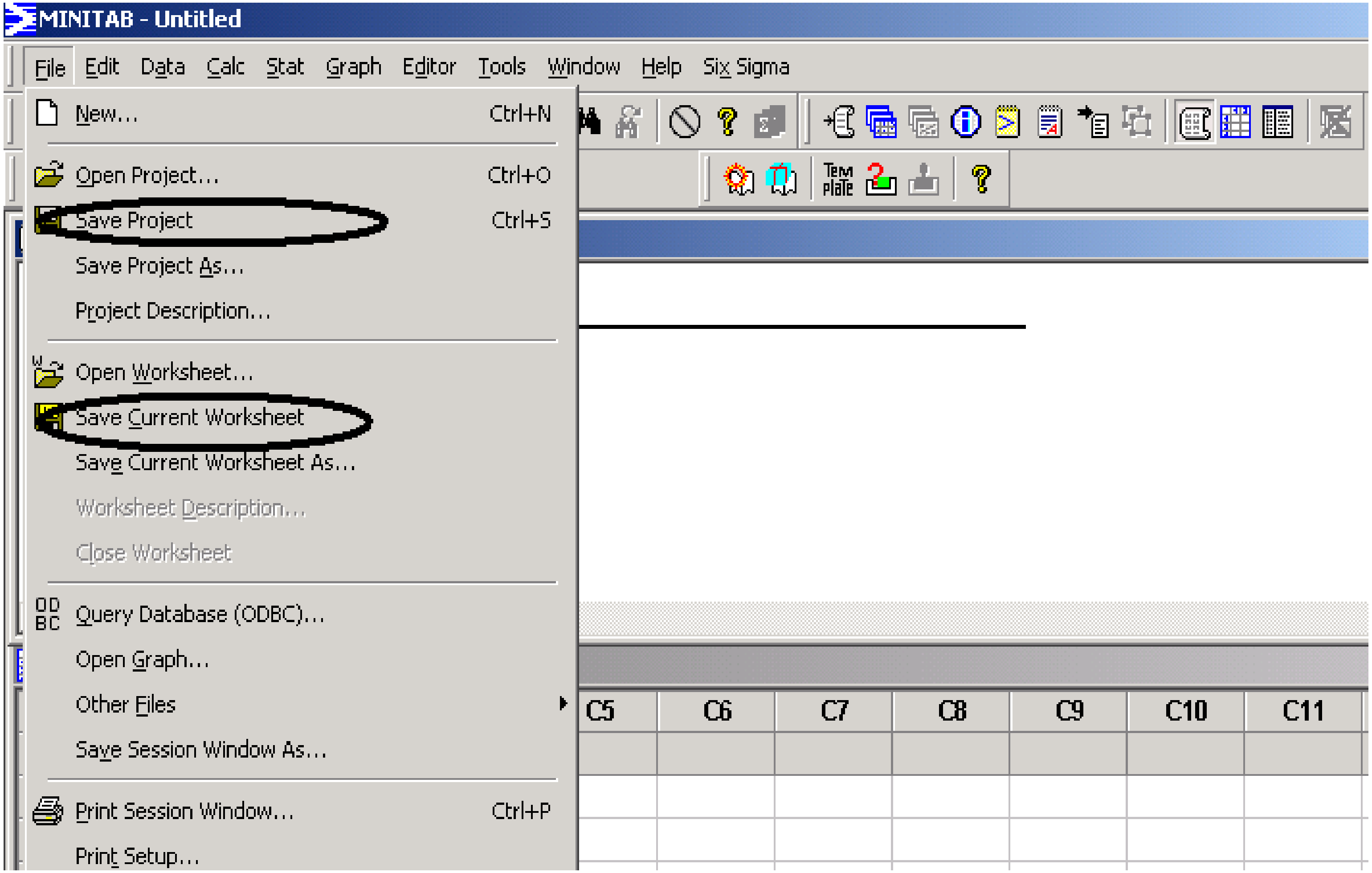
- Worksheet can be added to the existing project or can be opened in a new project

Minitab introduction and basics

- Minitab saves the work in two types:
  - Save Current Worksheet : The worksheet or data window can be saved. These type of file have an extension .mtw.
  - Save Project : The entire project analysis, data window, Graphs which we make during analysis are saved with an extension .mpj .

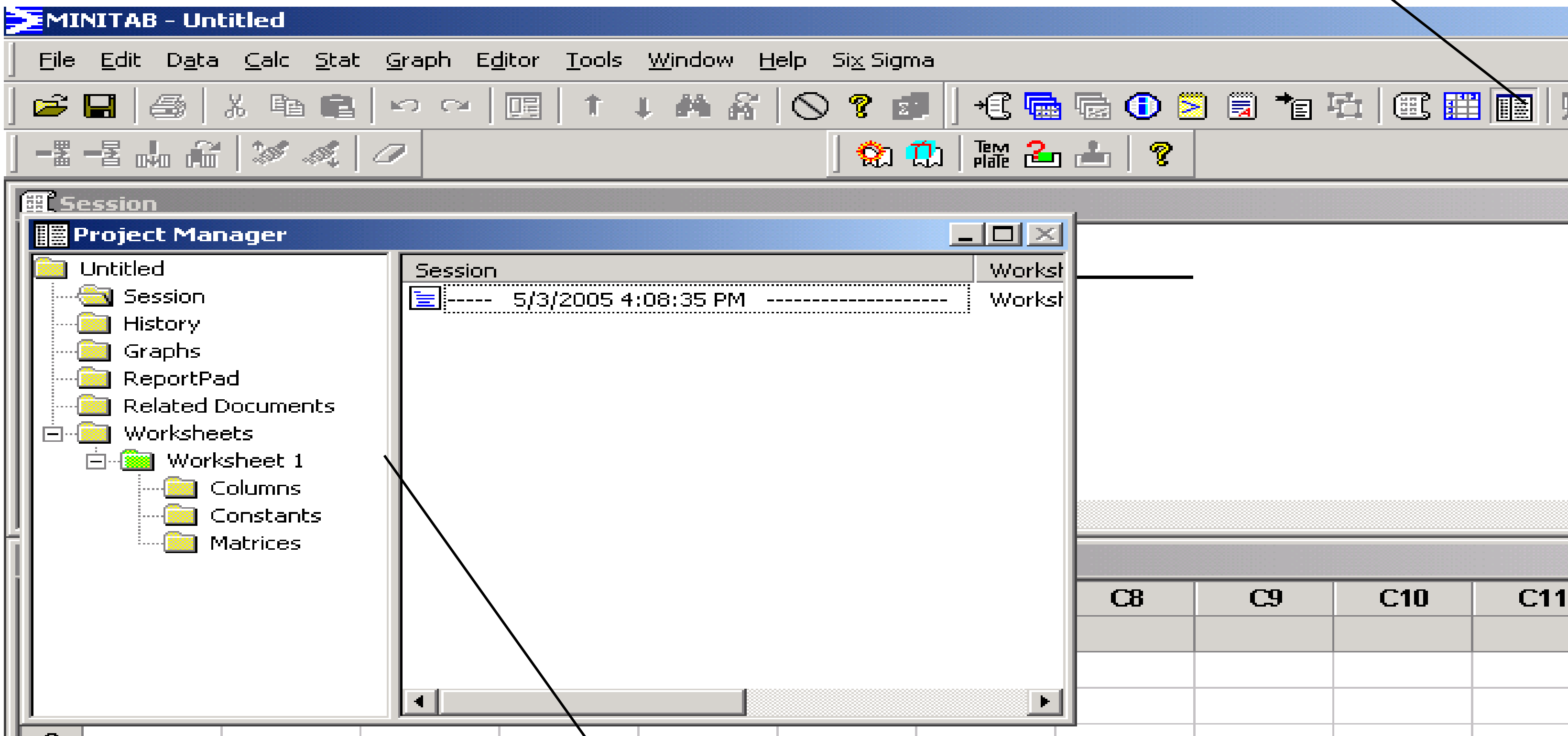
Minitab introduction and basics

Marked with black color in the file menu are the icons from where worksheet or Project or both can be saved.



Minitab introduction and basics

Project Manager icon after clicking here Project Manager will open



Project Manager Screen

Contd

Minitab introduction and basics

Project Manager- The Project Manager helps us to track the project elements such as worksheets,Session window output, graphs etc.

Following are the subfolders in Project Manager:

1. **Session window –** All the project related work are saved here like all statistical analysis, graphs. Any session window can be opened by double clicking them. The session window contains the following:

    I. Any statistical output generated by MINITAB command
    II. The command language used to generate
    III. Command prompt for entering session commands

    Session window is used to view the results of the analysis like mean, medians, p-values.

2. **History –** The history of the project is maintained here.

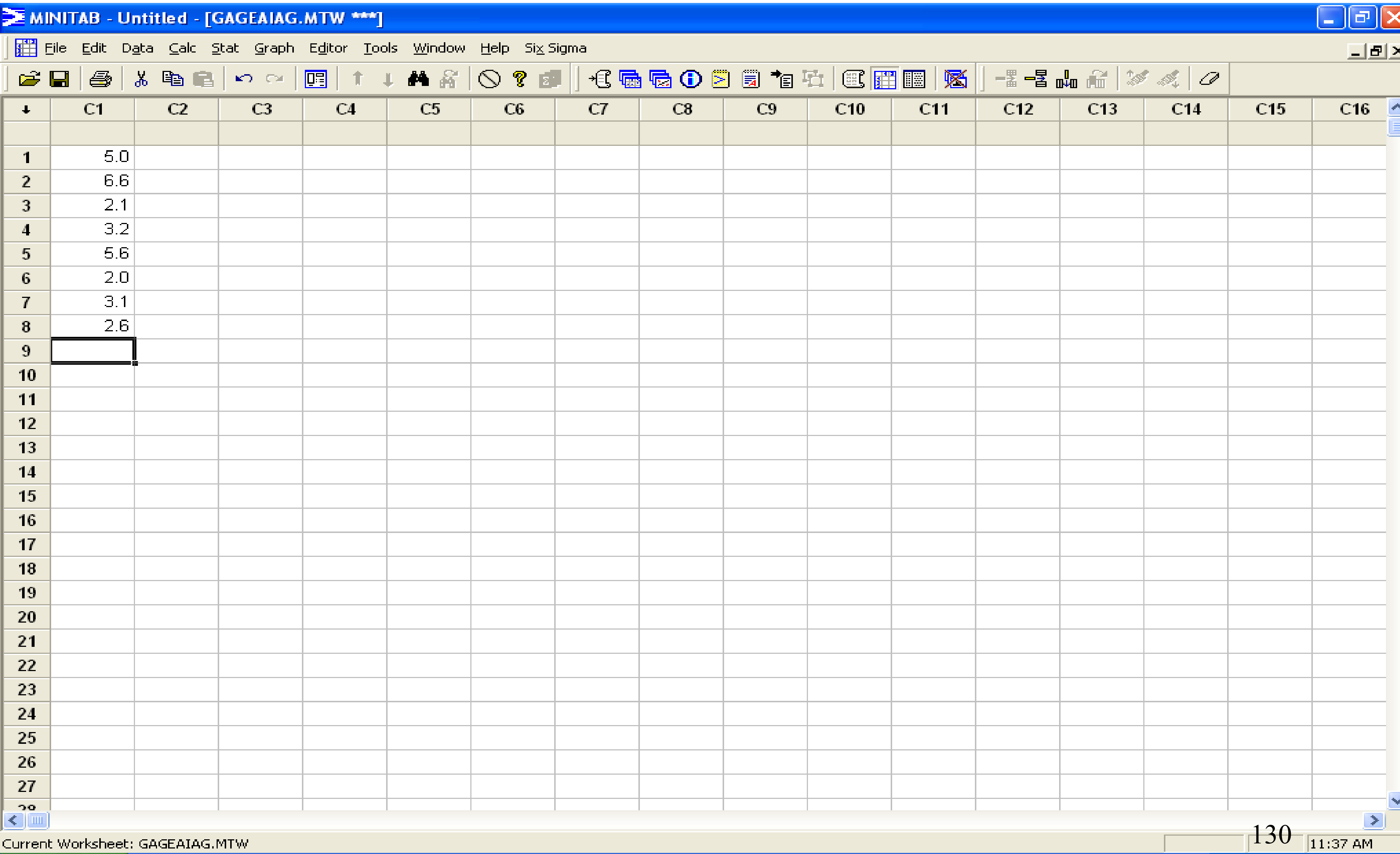
3. **Graphs –** All graphs are saved here, which we do during analysis.

4. **Report Pad –** All the reports either statistical analysis or graphs are appended here sequence-wise, once the appendage of some reports has done.

5. **Related Documents -** Related documents folder contains a list Of program files, documents, or internet URLs that are related to your Minitab Project.This folder is used to quickly access project-related, non-Minitab files for easy reference.

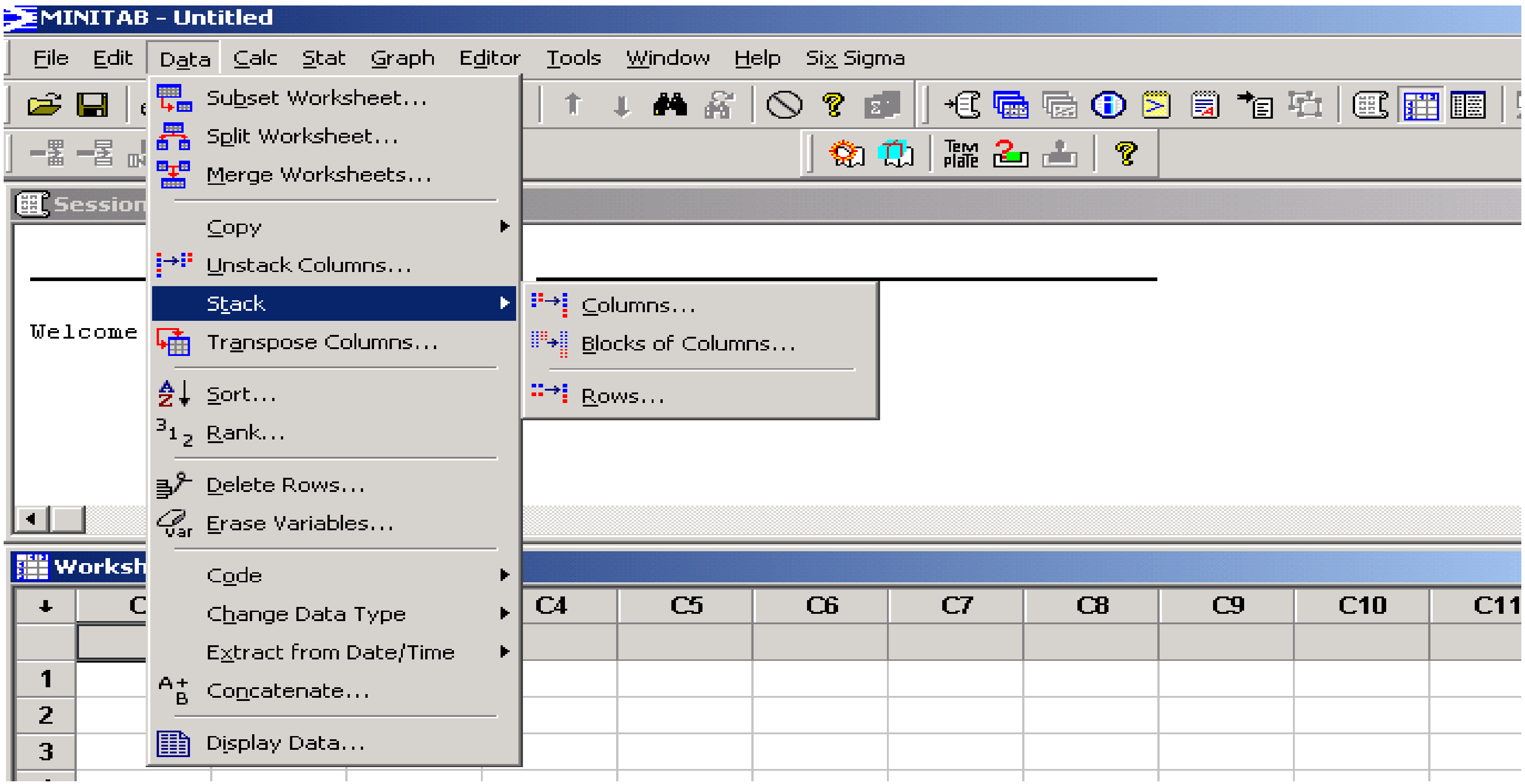
6. **Worksheet –** Data window is stored here.

Entering the data



Stacking

Stacking is used to arrange different columns or rows in one column or row. In many statistical technique data of same form are required in to be one column or one row.



Stacking

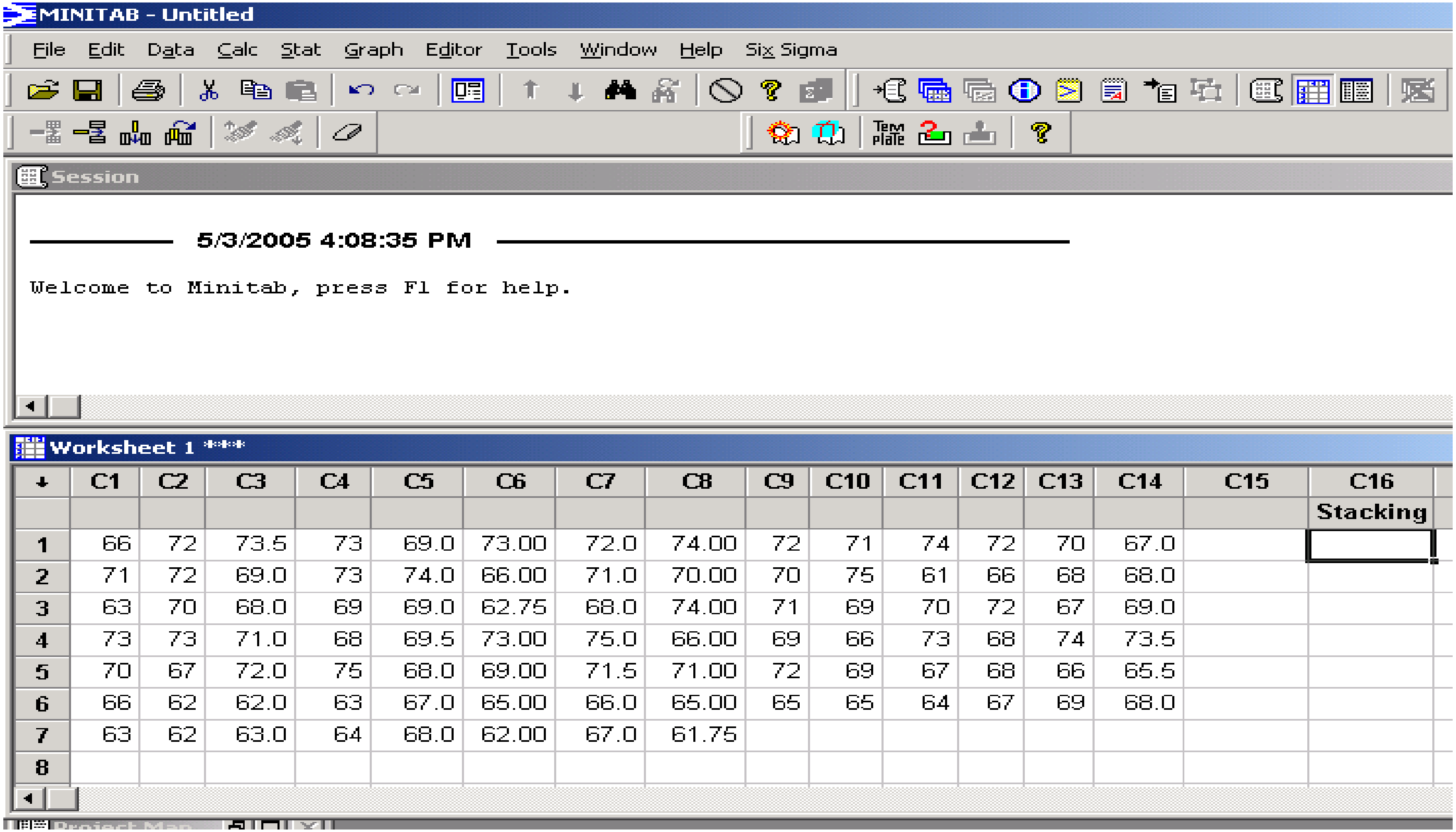
Following is the data set for bug resolution time(in mnts) per week.

66	72	73.5	73	69	73	72	74	72	71	74	72	70	67
71	72	69	73	74	66	71	70	70	75	61	66	68	68
63	70	68	69	69	62.7	68	74	71	69	70	72	67	69
73	73	71	68	69.5	73	75	66	69	66	73	68	74	73.5
70	67	72	75	68	69	71.5	71	72	69	67	68	66	65.5
66	62	62	63	67	65	66	65	65	65	64	67	69	68
63	62	63	64	68	62	67	61.7						

Import all the data or copy the data & paste in Data Window.

Stacking

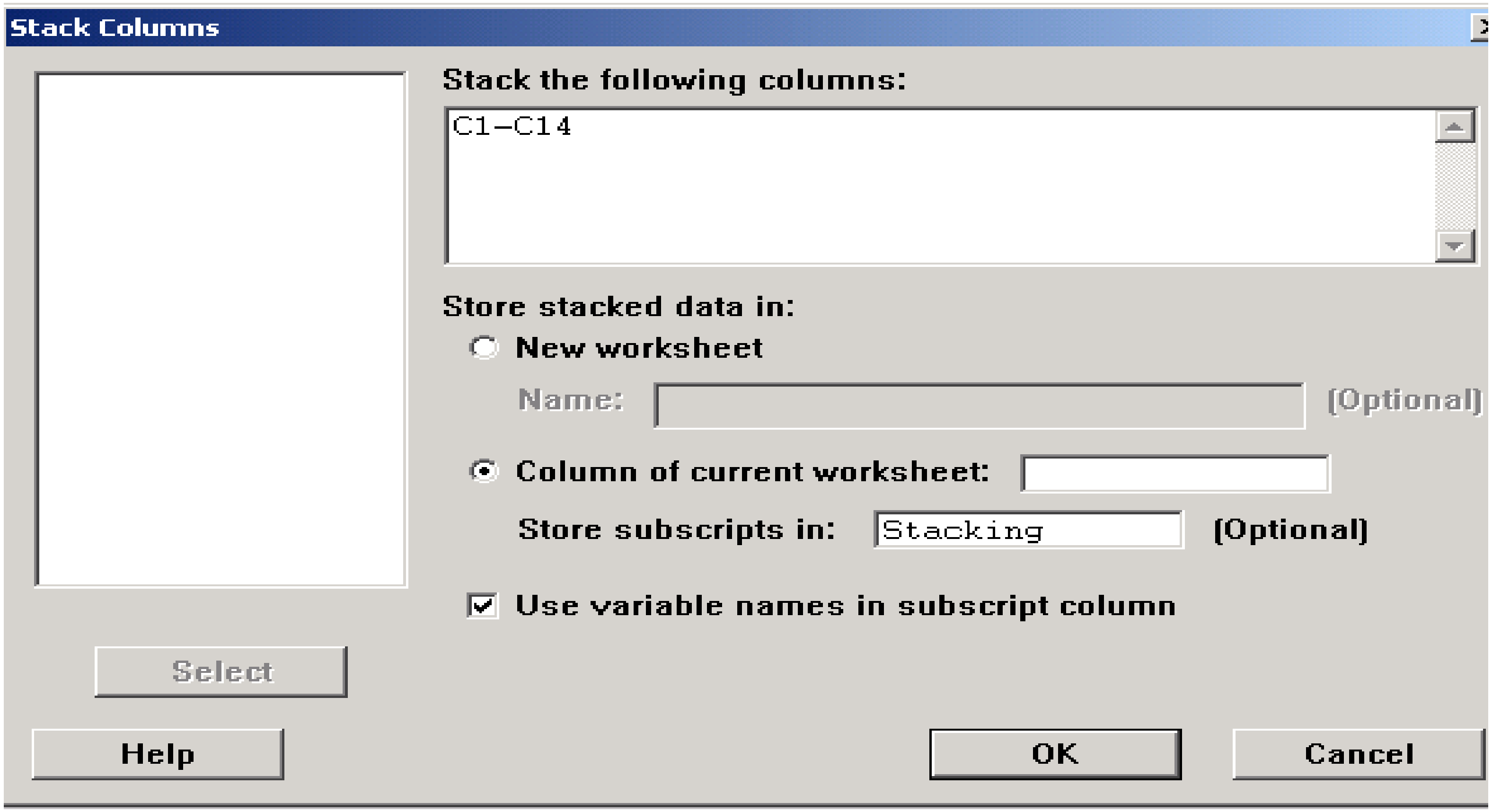
Following screen will appear-



↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
																Stacking
1	66	72	73.5	73	69.0	73.00	72.0	74.00	72	71	74	72	70	67.0		
2	71	72	69.0	73	74.0	66.00	71.0	70.00	70	75	61	66	68	68.0		
3	63	70	68.0	69	69.0	62.75	68.0	74.00	71	69	70	72	67	69.0		
4	73	73	71.0	68	69.5	73.00	75.0	66.00	69	66	73	68	74	73.5		
5	70	67	72.0	75	68.0	69.00	71.5	71.00	72	69	67	68	66	65.5		
6	66	62	62.0	63	67.0	65.00	66.0	65.00	65	65	64	67	69	68.0		
7	63	62	63.0	64	68.0	62.00	67.0	61.75								
8																

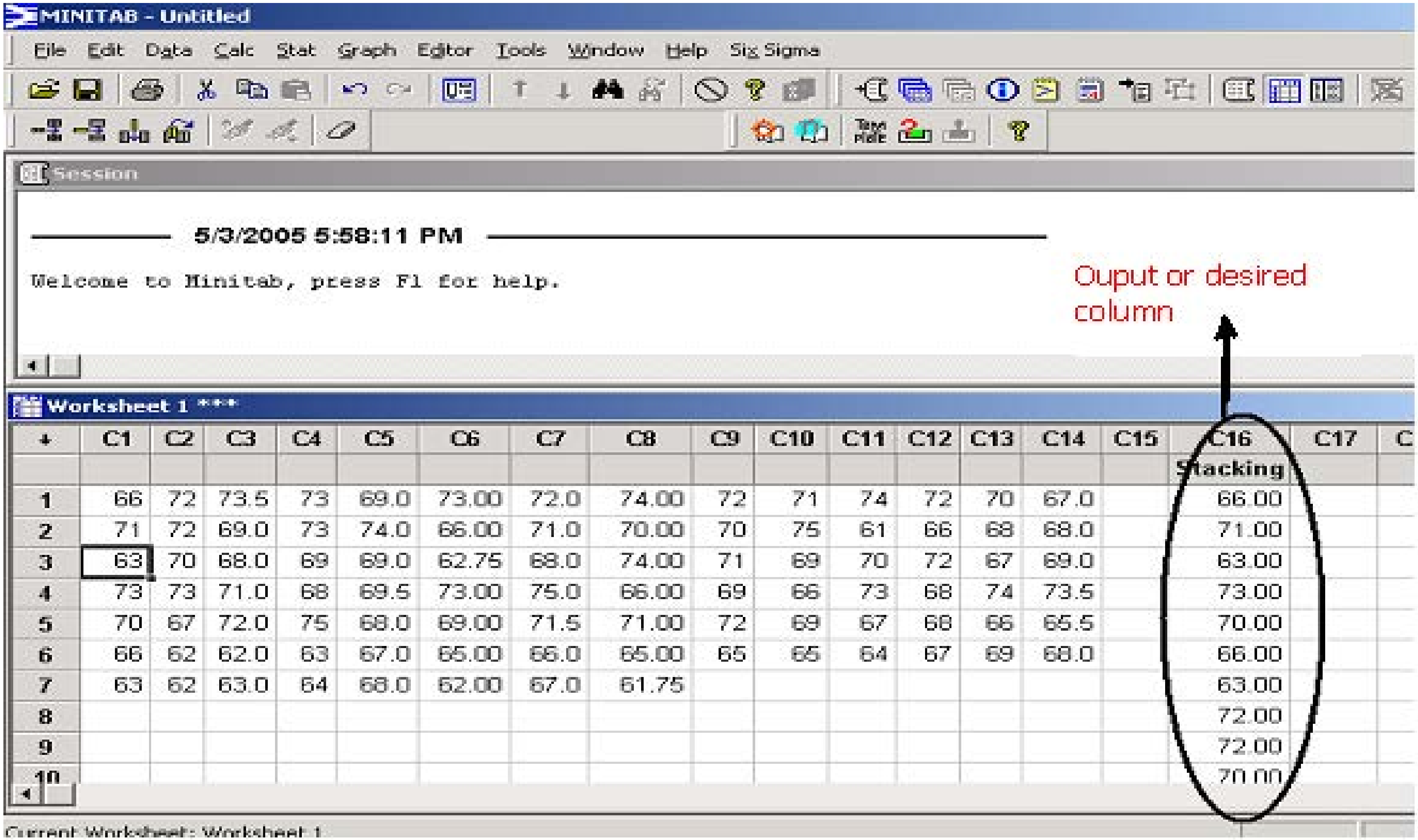
Stacking

Perform the following steps for Stacking–
Choose *Data > Stack > Columns.*
Complete the dialog as shown below.



Stacking

The Result is shown below

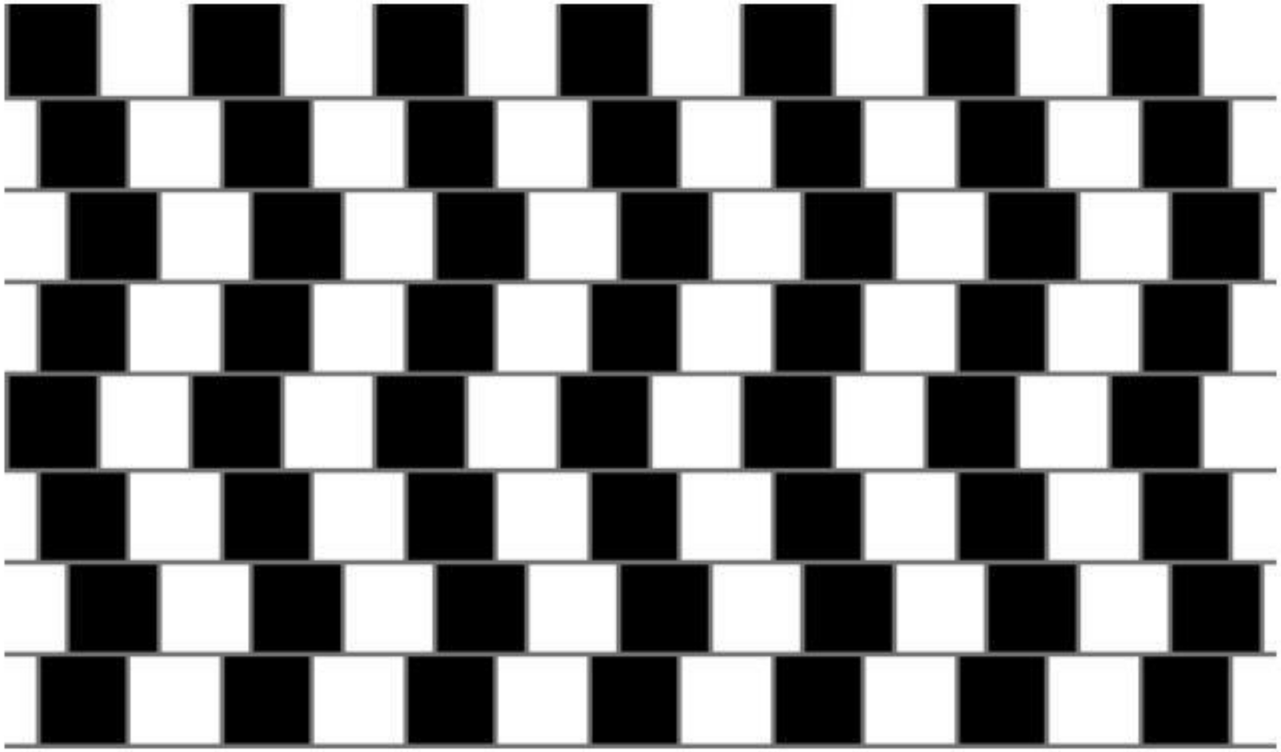


	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
																Stacking	
1	66	72	73.5	73	69.0	73.00	72.0	74.00	72	71	74	72	70	67.0		66.00	
2	71	72	69.0	73	74.0	66.00	71.0	70.00	70	75	61	66	68	68.0		71.00	
3	63	70	68.0	69	69.0	62.75	68.0	74.00	71	69	70	72	67	69.0		63.00	
4	73	73	71.0	68	69.5	73.00	75.0	66.00	69	66	73	68	74	73.5		73.00	
5	70	67	72.0	75	68.0	69.00	71.5	71.00	72	69	67	68	66	65.5		70.00	
6	66	62	62.0	63	67.0	65.00	66.0	65.00	65	65	64	67	69	68.0		66.00	
7	63	62	63.0	64	68.0	62.00	67.0	61.75								63.00	
8																72.00	
9																72.00	
10																70.00	

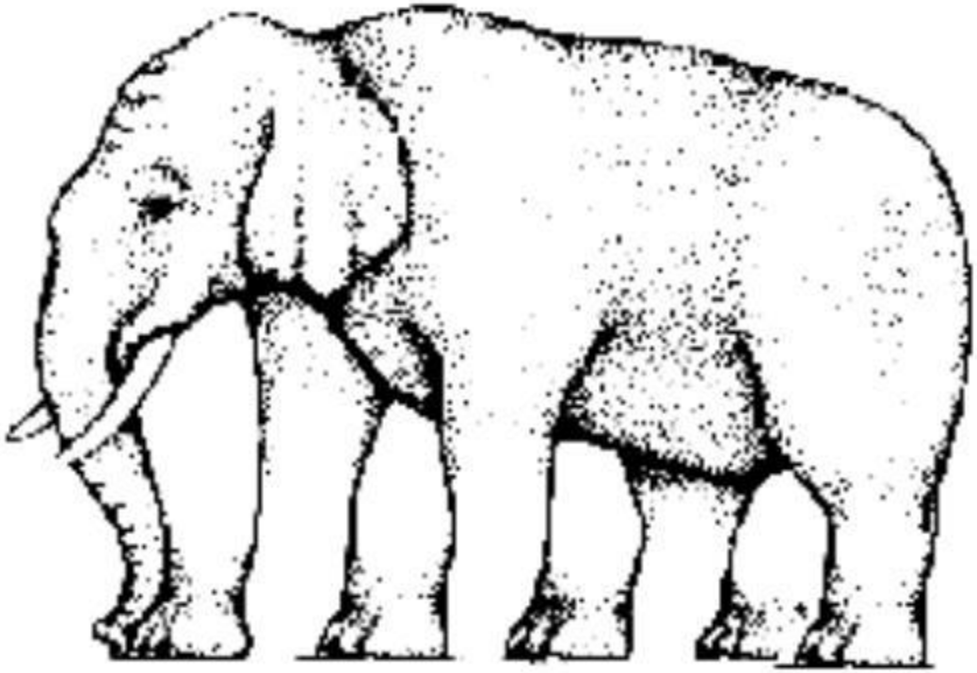
Measurement System Analysis

Count the Occurrence of letter 'l' in the Paragraph

- A country preacher was walking the back-road near a church. He became thirsty so decided to stop at a little cottage and ask for something to drink. The lady of the house invited him in and in addition to something to drink, she served him a bowl of soup by the fire. There was a small pig running around the kitchen. The pig was constantly running up to the visitor and giving him a great deal of attention. The visiting pastor commented that he had never seen a pig this friendly. The housewife replied: "Ah, he's not that friendly. Actually, that's his bowl you're using!"



Are the horizontal lines parallel or do they slope?



How many legs does this elephant have?

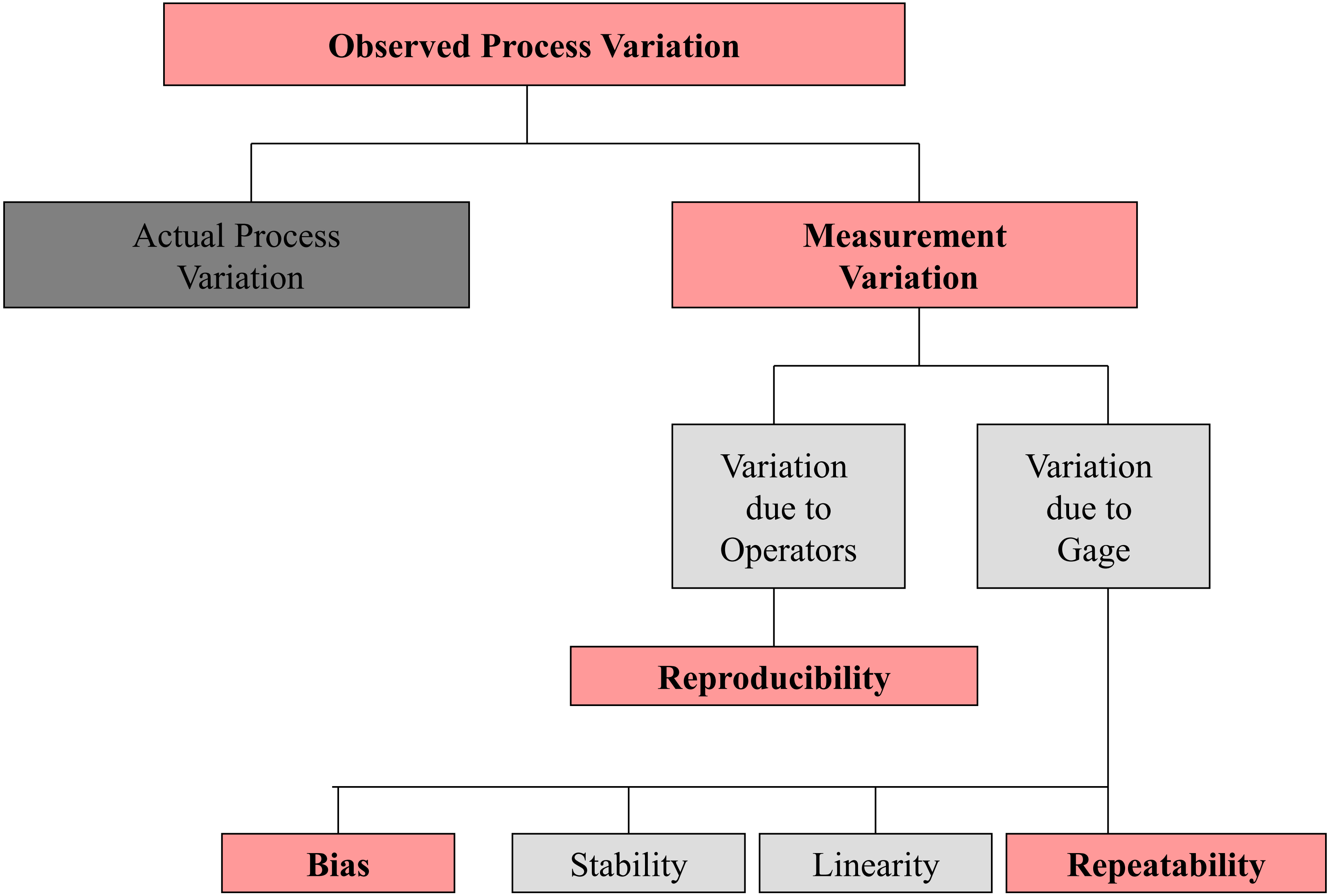
Look at the chart and say the COLOUR not the word

YELLOW BLUE ORANGE
BLACK RED GREEN
PURPLE YELLOW RED
ORANGE GREEN BLACK
BLUE RED PURPLE
GREEN BLUE ORANGE

Left – Right Conflict

Your right brain tries to say the colour but your left brain insists on reading the word.

Possible Sources Of Variation



To Address Actual Process Variability; The Variation Due To The Measurement System Must First Be Identified And Separated From That Of The Process

Measurement System Analysis–Objectives

- Recognize that observed variation of a product/process includes the true variation of the product/process & the variation due to the measurement system
- Identify & describe possible sources of variation in a measurement process
- Describe the importance of a validated measurement system
- Describe the terms precision, accuracy & resolution in relation to MSA
- Use appropriate tools to validate measurement system, analyze, and interpret results
  - Gage R&R for continuous data
  - Attribute R&R for discrete data

One of the objectives of the Measure Phase is to validate your measurement system. A Gage R&R Study will help us do this!

The focus of this module is to review the methodology and tools to validate your measurement system.

MSA = Measurement System Analysis

Gage R&R = Gage Repeatability & Reproducibility

Why is MSA important?

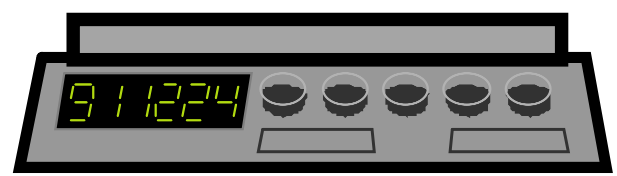
Data is only as good as the process that MSA identifies how much variation is present in the measurement process.   Understanding measurement variation is necessary for identifying “true” process variation and maximizing true Y improvements.

Without MSA, you run the risk of making decisions based on an inaccurate picture of your MSA helps direct efforts aimed at decreasing measurement variation.

Excessive measurement variation distorts our understanding of what the customer feels

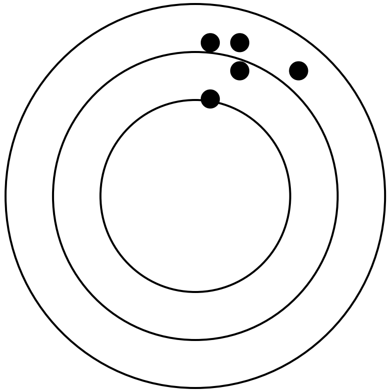
What Are Some Types of Gages?

- Variable Gages
  - Heart Rate monitors
  - Gas content monitors
  - Graduated cylinders
  - Pressure gages
  - Thermometers
- Attribute Gages
  - Spacer gages
  - Chromatic Standards
  - Visual inspection (pass/fail)

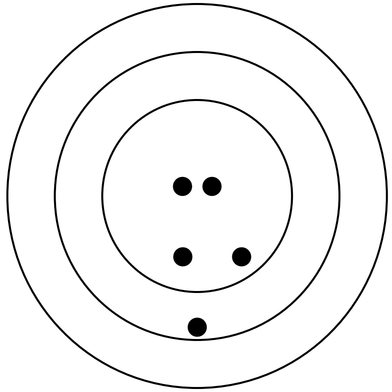


All types of gages can be evaluated for R&R.

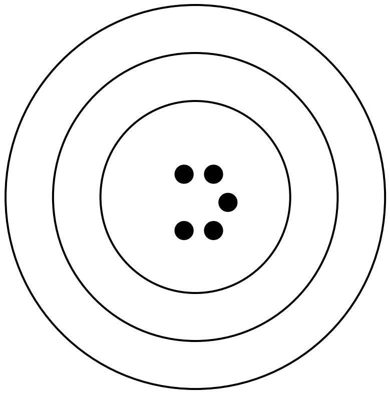
Measurement System Errors



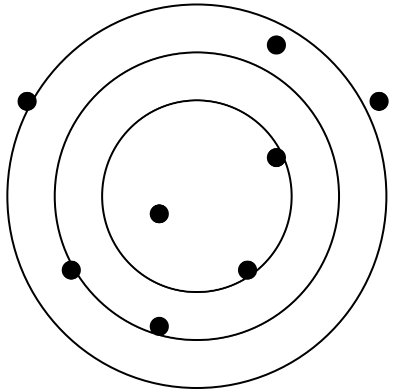
Precise NOT Accurate



Accurate NOT Precise

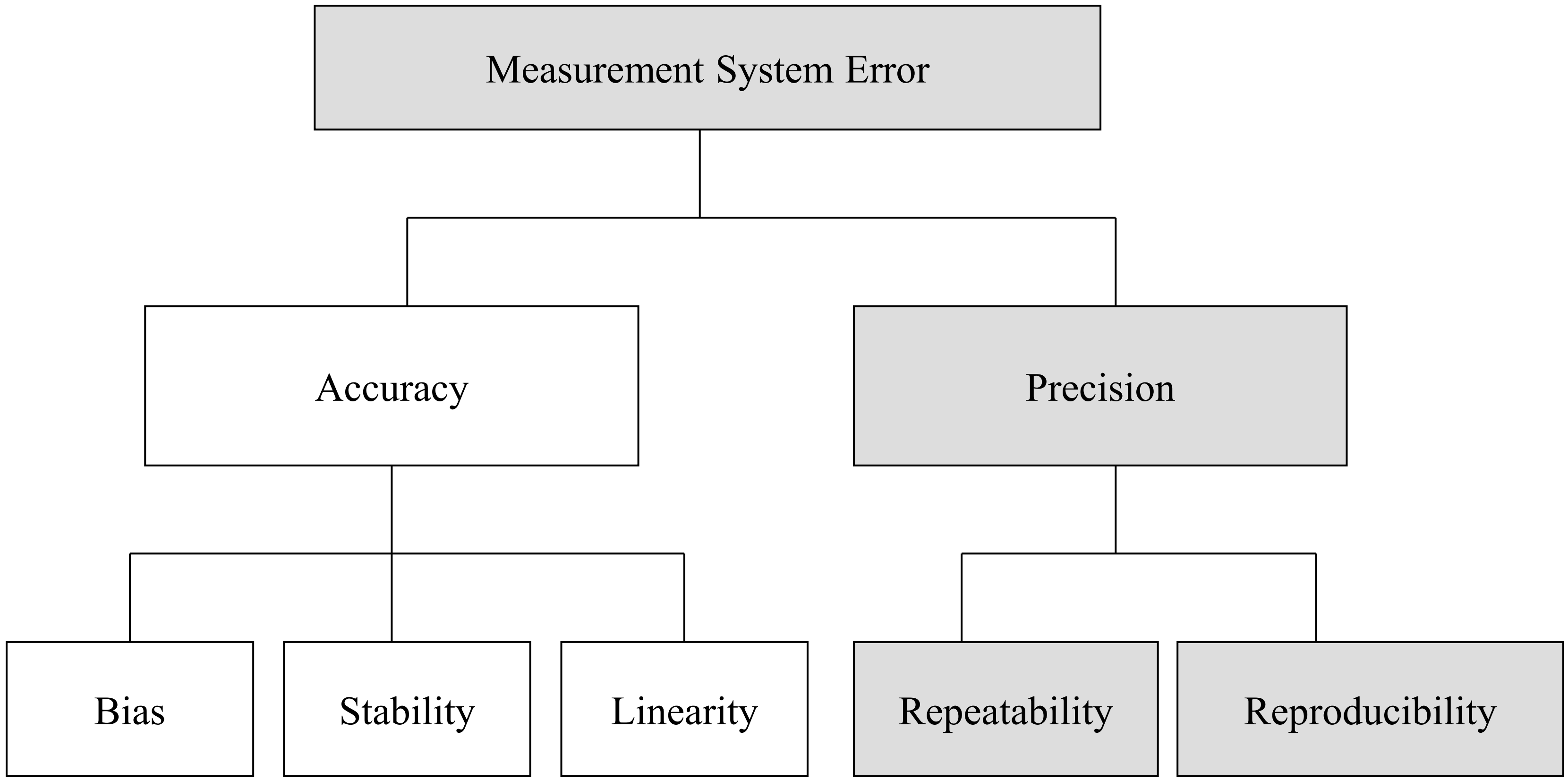


Accurate AND Precise



Neither Accurate, Nor Precise

Accuracy and Precision



Measurement System Characteristics

Accuracy

The difference between the average of observed values and the standard.

Stability

Variation in measurement when the same person measures the same unit using the same measuring gauge over extended period of time.

Linearity

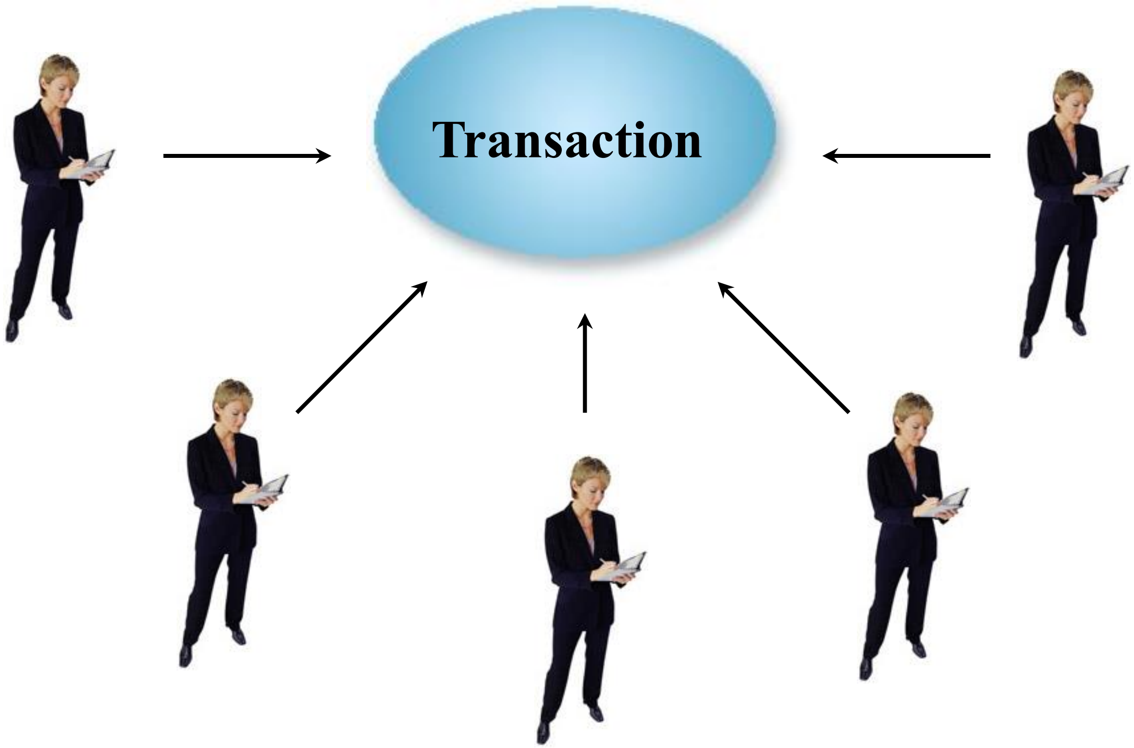
The consistency of the measurement across the entire range of the measuring gauge

Gage Repeatability

Gage repeatability is a measure of how consistently the same person (or system) measures the same event over time using the same measurement system.

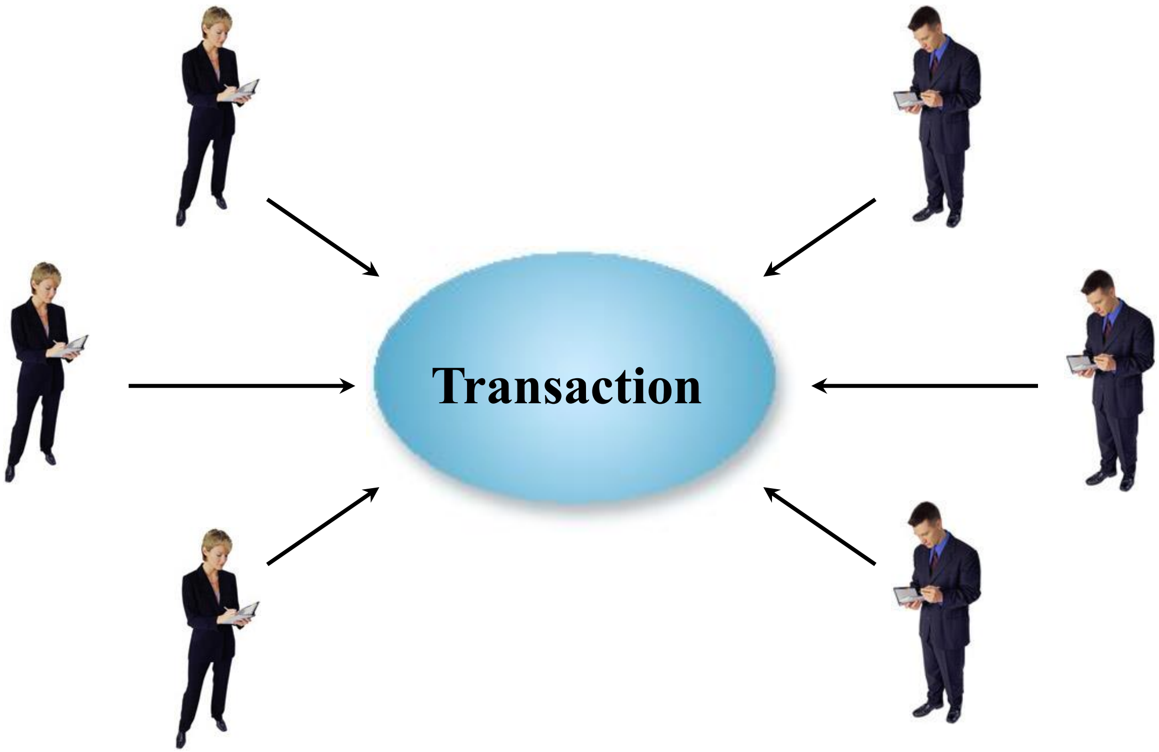
To find this value, we record how the same operator or system repeatedly measures the same event with the same measurement system.

Since the event does not change, any change in the measurements must be due to variation in the measurement process.

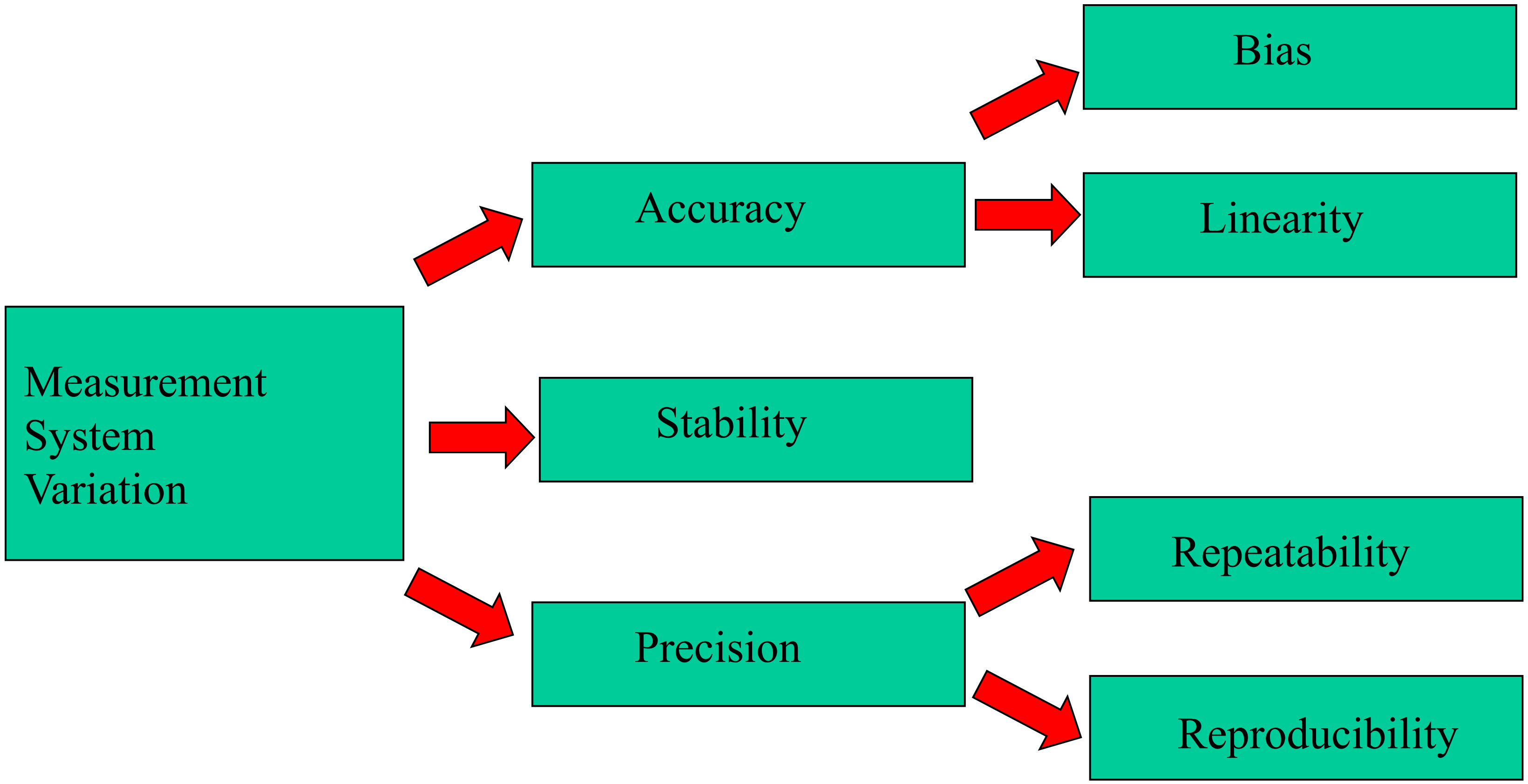


Gage Reproducibility

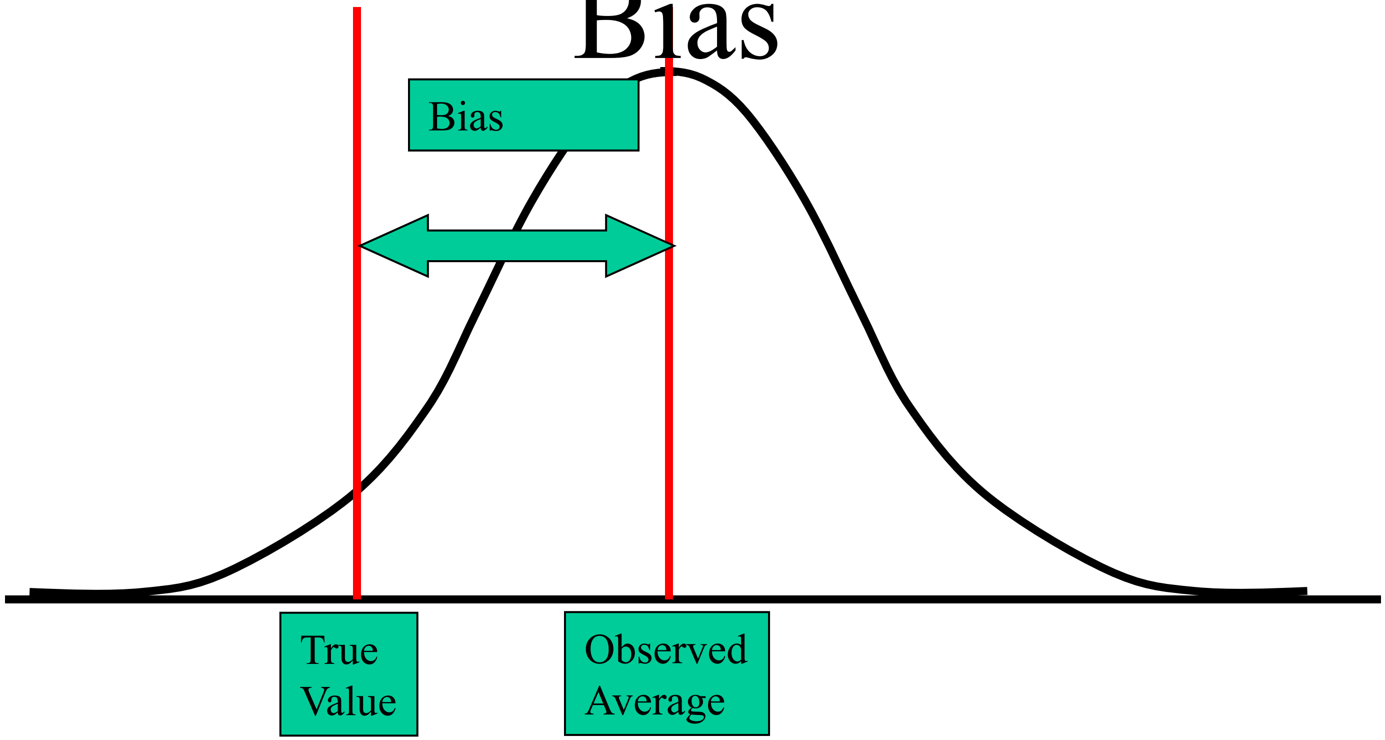
Gage reproducibility is a measure of how consistently several operators or measurement systems measure the same event over time. To find this value, we have several people or systems repeatedly measure the same event. We then look for differences in the results between the people or systems.



Measurement System Variation

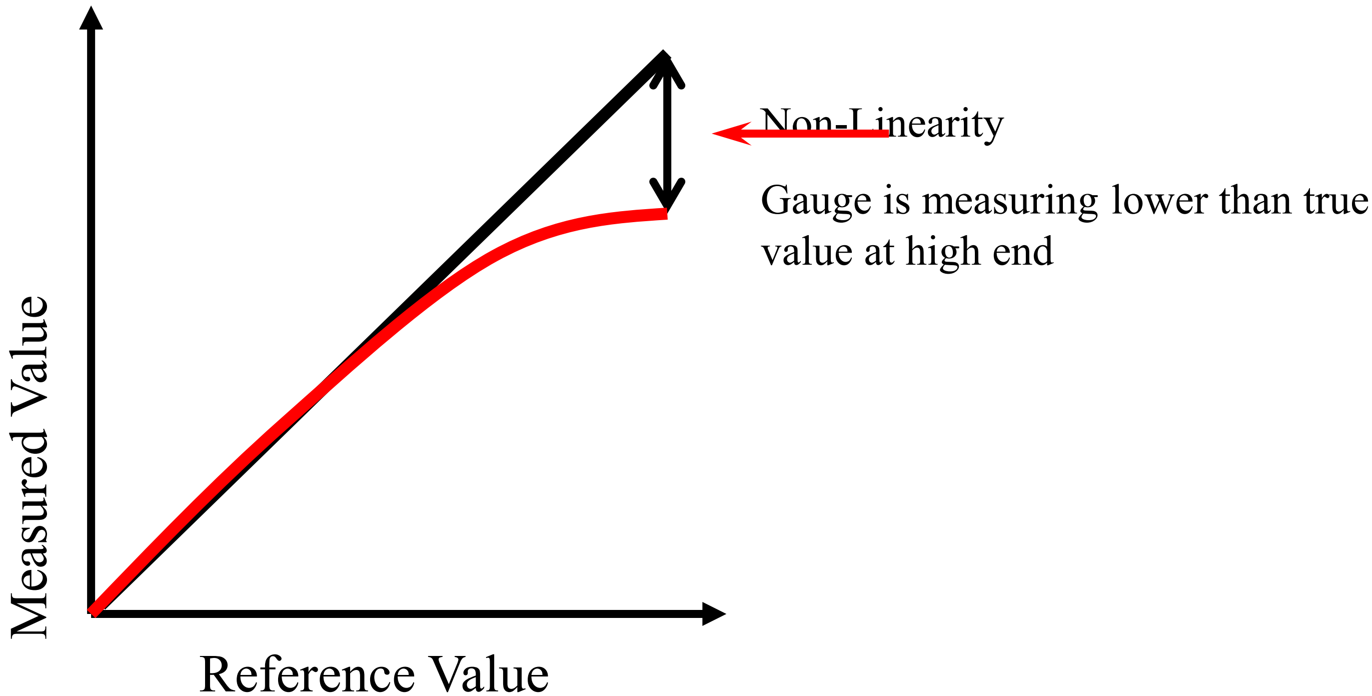


Bias



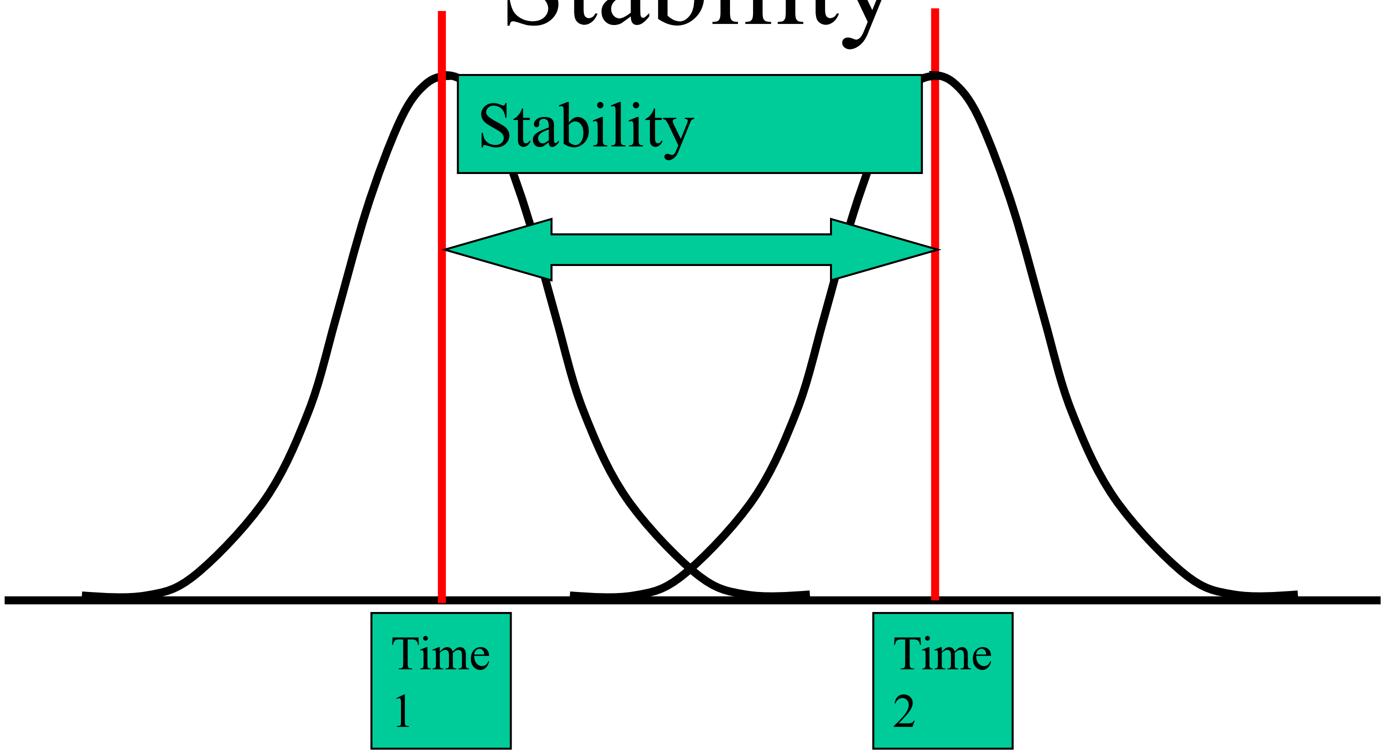
Bias is the difference between the observed average of the measurements and the true value.

Linearity



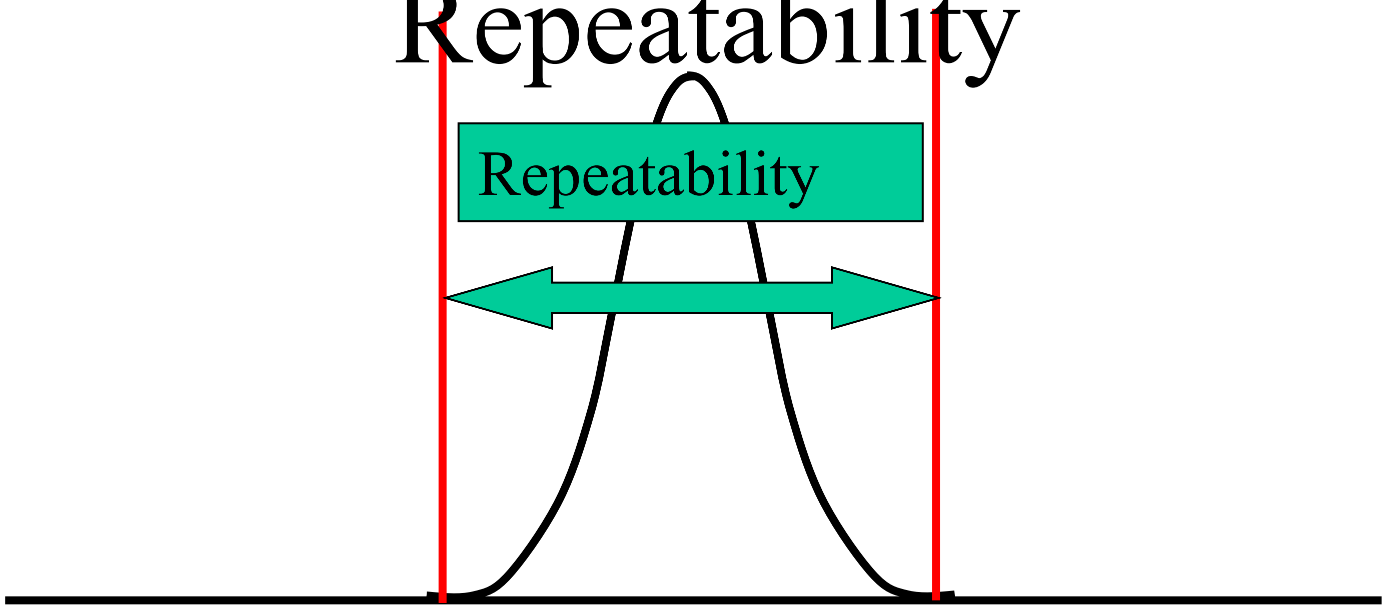
Linearity is the difference in bias values over the expected operating range of the measurement gauge.

Stability



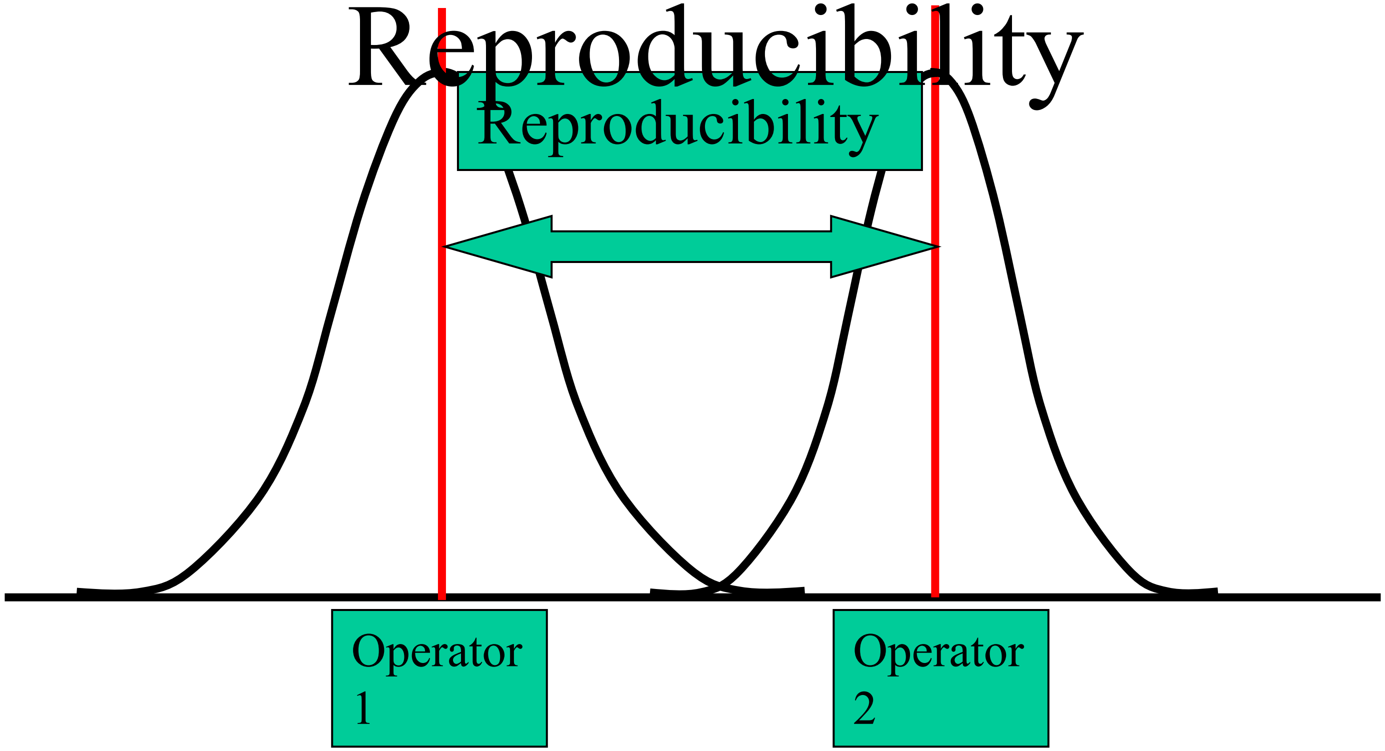
Stability is the variation (differences) in the average over extended periods of time using the same gauge and appraiser to repeatedly measure the same part

Repeatability



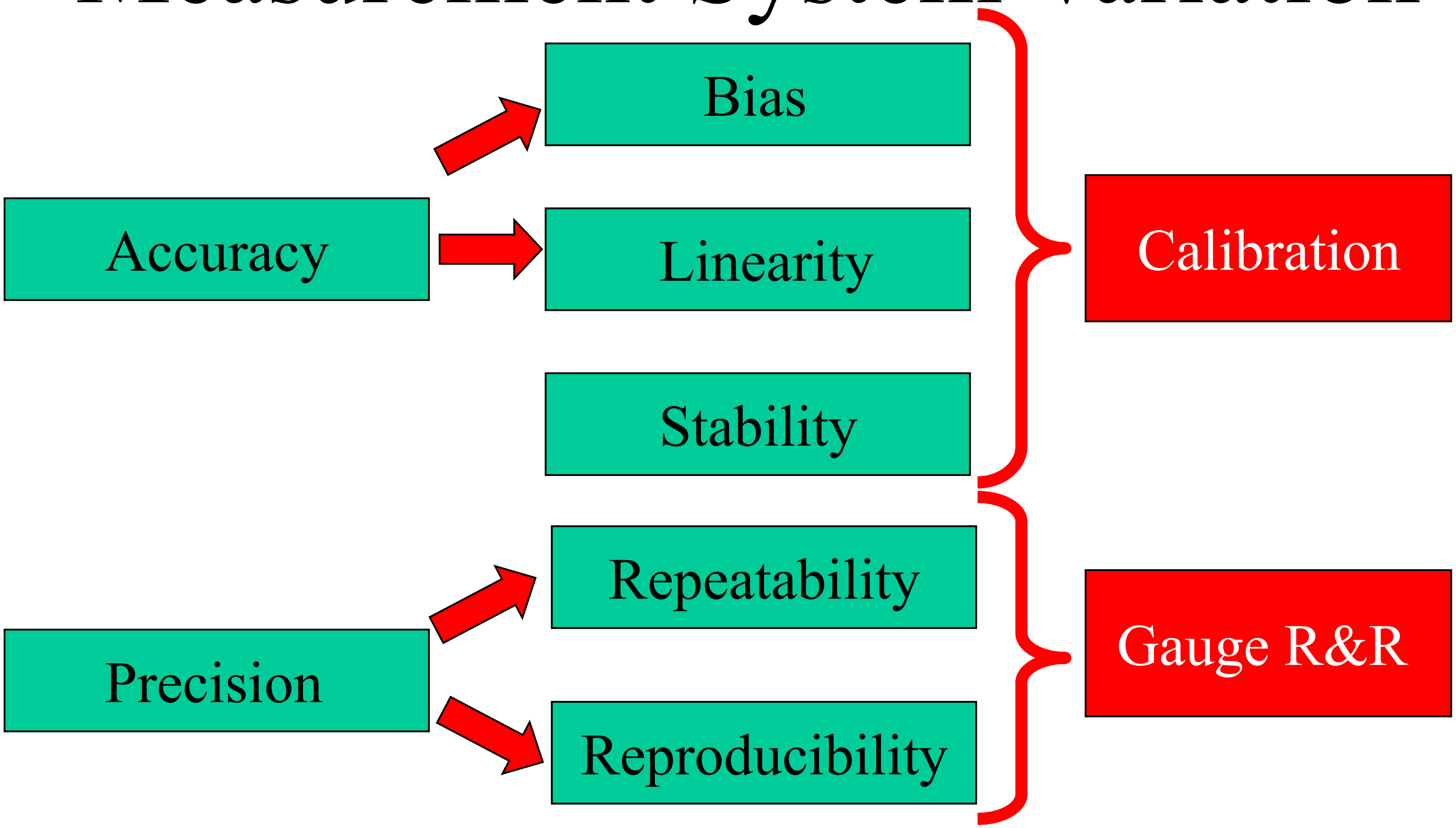
Repeatability is the variation between successive measurements of the same part, same characteristic, by the same person using the same gauge.

Reproducibility



Reproducibility is the difference in the average of the measurements made by different people using the same instrument when measuring the identical characteristic on the same pieces.

Measurement System Variation



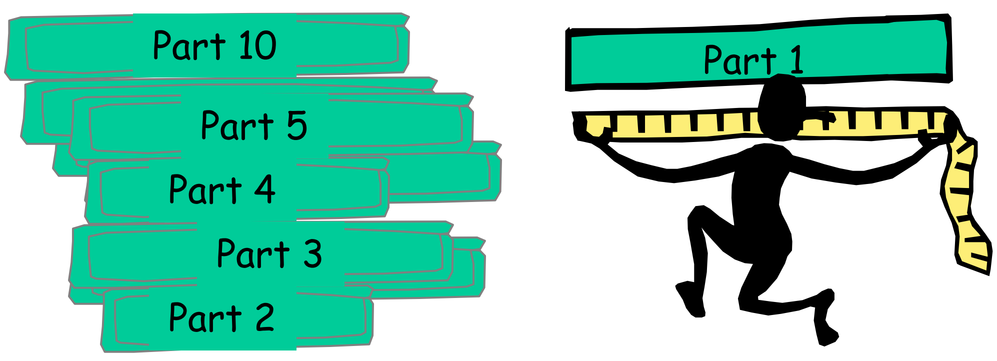
Calibration

- The Bias of a gauge can be assessed by repeat measurements of a known reference unit
- This can be extended across the operating range of the gauge in a *Gauge Linearity Study*
- The Stability of the gauge can be assessed by control charting a reference unit
- Should not routinely recalibrate, instead if reference unit tests outside the control limits, then re-calibrate
- If measurement device requires frequent recalibration, attempt to improve stability

Variable Gauge R&R

Variable Gauge R&R

- Requirements:
- A minimum of two operators (recommend 3 or 4)
- At least 10 parts which should be chosen to represent the full range of manufacturing variation (it may be acceptable to use fewer parts in some special cases)
- Each part should be measured two or three times in a random order
- Operators should not be aware of the previous result when measuring the same part

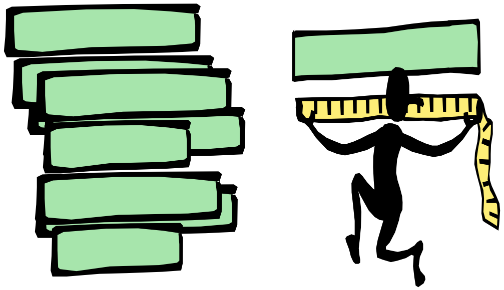


Variable Gauge R&R

There are two methods available:

1. Analysis of Variance (ANOVA)

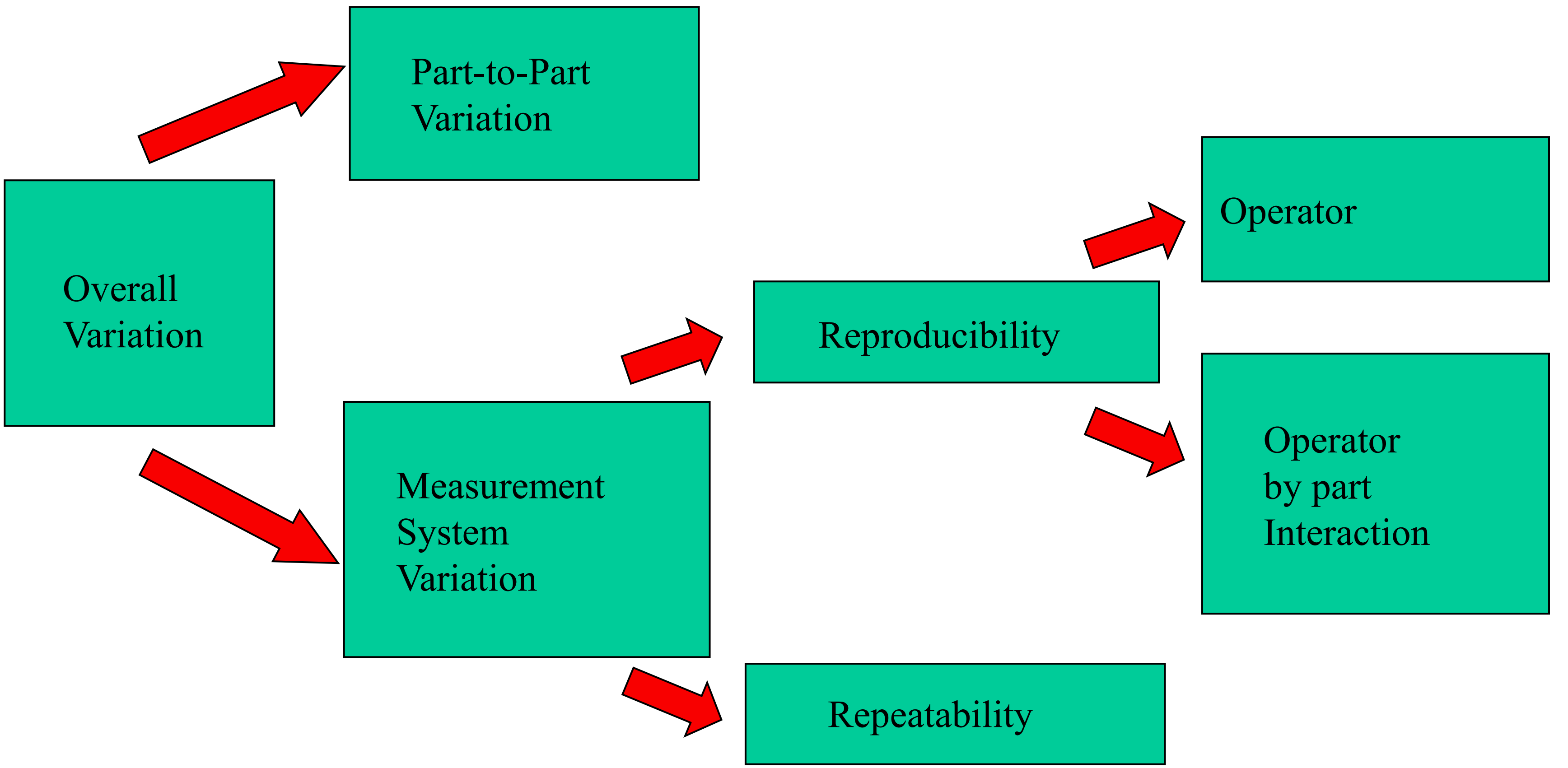
2. X-Bar and R



The ANOVA method is:

- the recommended approach
- takes into account any interactive effect between operator and part

Variable Gauge R&R



We want the Part-to-Part component to be large!

Variable Gauge R&R - Example

Part	Operator 1	Operator 2	Operator 3
1	0.65	0.55	0.50
1	0.60	0.55	0.55
2	1.00	1.05	1.05
2	1.00	0.95	1.00
3	0.85	0.80	0.80
3	0.80	0.75	0.80
4	0.85	0.80	0.80
4	0.95	0.75	0.80
5	0.55	0.40	0.45
5	0.45	0.40	0.50
6	1.00	1.00	1.00
6	1.00	1.05	1.05
7	0.95	0.95	0.95
7	0.95	0.90	0.95
8	0.85	0.75	0.80
8	0.80	0.70	0.80
9	1.00	1.00	1.05
9	1.00	0.95	1.05
10	0.60	0.55	0.85
10	0.70	0.50	0.80

Open Worksheet: Gauge R&R

Variable Gauge R&R - Minitab

The Part numbers being measured

Operators performing measurements

Each operator measures each part twice

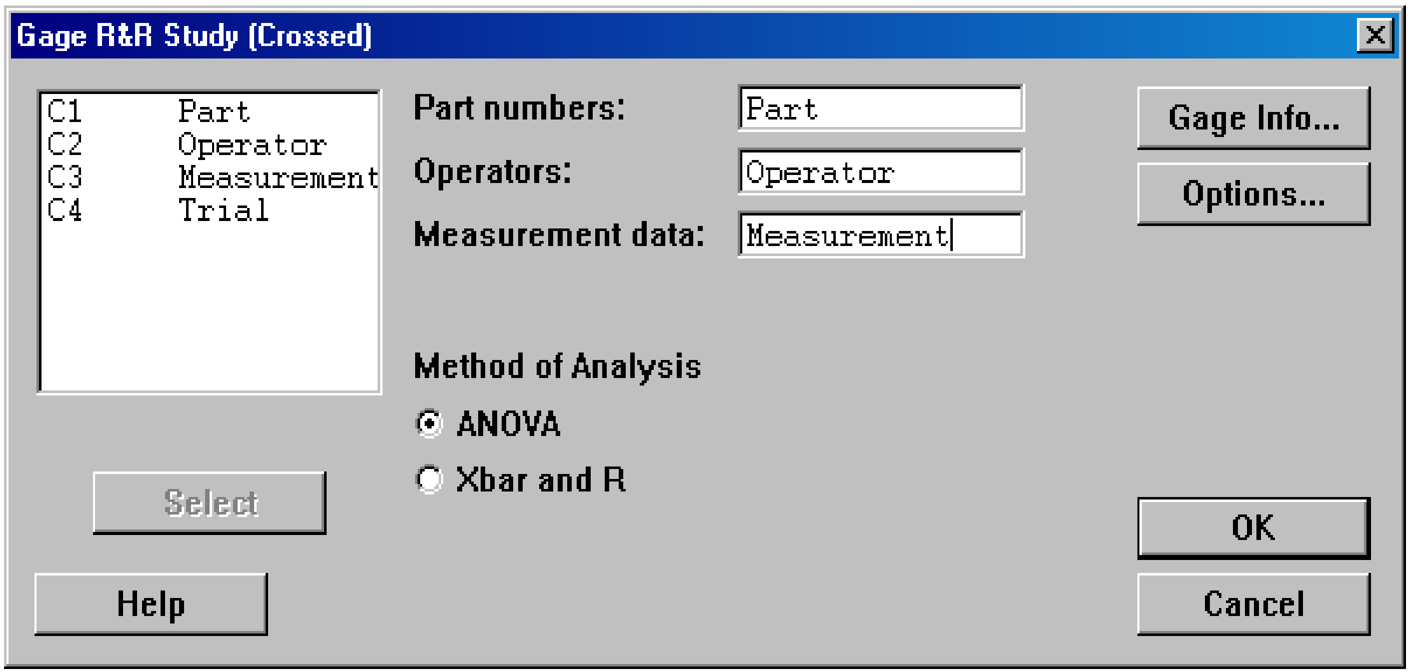
Individual measurements

↓	C1	C2	C3	C4
	Part	Operator	Measurement	Trial
1	1	1	0.65	1
2	1	1	0.60	2
3	2	1	1.00	1
4	2	1	1.00	2
5	3	1	0.85	1
6	3	1	0.80	2
7	4	1	0.85	1
8	4	1	0.95	2
9	5	1	0.55	1
10	5	1	0.45	2
11	6	1	1.00	1
12	6	1	1.00	2
13	7	1	0.95	1
14	7	1	0.95	2
15	8	1	0.85	1
16	8	1	0.80	2
17	9	1	1.00	1
18	9	1	1.00	2
19	10	1	0.60	1
20	10	1	0.70	2
21	1	2	0.55	1
22	1	2	0.55	2
23	2	2	1.05	1
24	2	2	0.95	2
25	3	2	0.80	1
26	3	2	0.75	2
27	4	2	0.80	1
28	4	2	0.75	2

In Minitab the data is entered in single columns

Variable Gauge R&R - Minitab

Stat>Quality Tools>Gage Study>Gage R& R (Crossed)
Enter Part, Operator, Measurement
Check ANOVA Method



Variable Gauge R&R - Minitab

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	2.05871	0.228745	39.7178	0.000
Operator	2	0.04800	0.024000	4.1672	0.033
Part * Operator	18	0.10367	0.005759	4.4588	0.000
Repeatability	30	0.03875	0.001292		
Total	59	2.24913			

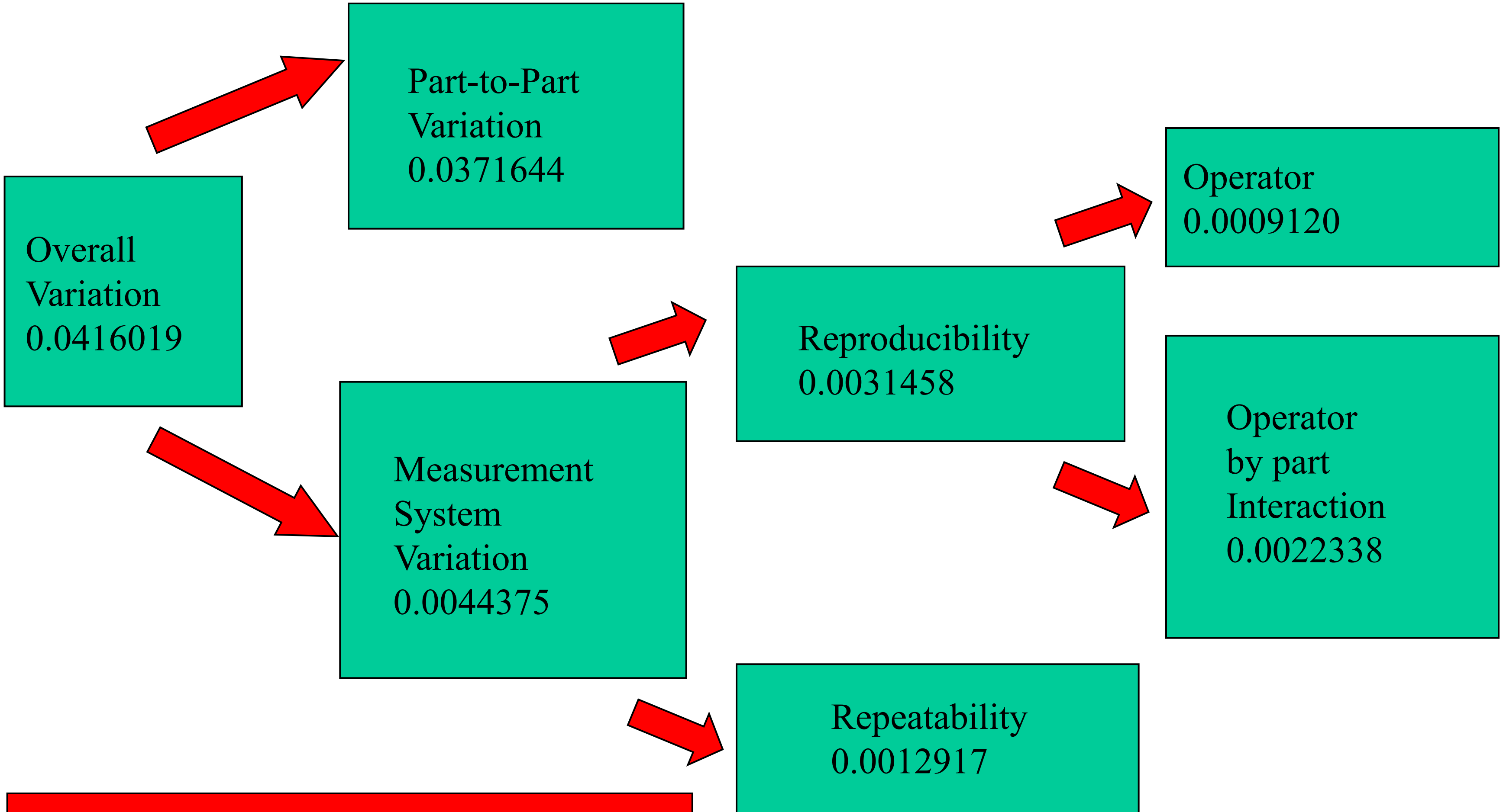
$p < 0.05$ so all terms significant

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0044375	10.67
Repeatability	0.0012917	3.10
Reproducibility	0.0031458	7.56
Operator	0.0009120	2.19
Operator*Part	0.0022338	5.37
Part-To-Part	0.0371644	89.33

Estimates of Variances for each source

Variance Component Estimates



Variances are additive!

Gage R and R ANOVA Method: Example

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Call Number	2	592.667	296.333	205.154	0.000
Operator Num	2	6.889	3.444	2.385	0.208
Call Number * Operator Num	4	5.778	1.444	7.800	0.001
Repeatability	18	3.333	0.185		
Total	26	608.667			

Gage R&R

Source	**VarComp**	**%Contribution (of VarComp)**
Total Gage R&R	**0.8272**	**2.46**
Repeatability	**0.1852**	**0.55**
Reproducibility	**0.6420**	**1.91**
Operator Num	**0.2222**	**0.66**
Operator Num*Call Number	**0.4198**	**1.25**
Part-To-Part	**32.7654**	**97.54**
Total Variation	**33.5926**	**100.00**

The Total Gage R&R value under % contribution shows the measurement system error for this test, in this case 2.46% of the variation in the data comes from the measurement system. We like it to be less than **10%,** so this measurement system is acceptable.

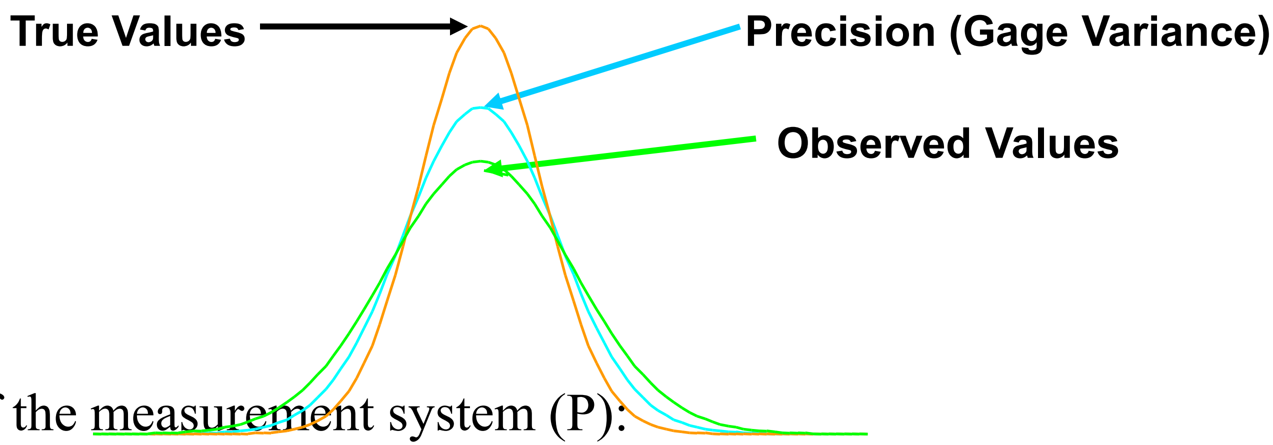
The remaining variation comes from Part-to-Part variation. In this study, 97.54% of the variation was due to variation in performance of the actual call cycle time – true process variation.

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.90948	5.4569	15.69
Repeatability	0.43033	2.5820	7.42
Reproducibility	0.80123	4.8074	13.82
Operator Num	0.47140	2.8284	8.13
Operator Num*Call Number	0.64788	3.8873	11.18
Part-To-Part	5.72411	34.3447	98.76
Total Variation	5.79591	34.7755	100.00

Number of Distinct Categories = 8

Measurement System Metrics

- Gage R&R Output → Gage Variance ($\sigma_{\text{measurement system}}$)



- Precision of the measurement system (P):

$$P = 6 \times \sqrt{\sigma_{MS}^2} = 6 \times \sigma_{MS}$$

  – Precision includes both repeatability and reproducibility

Why use a value of 6?

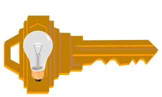
Measurement System Metrics – P/T

- Precision to Tolerance Ratio
  - Addresses the fraction of the tolerance taken up by the gage variance

$$\boxed{Tolerance = USL - LSL}$$

$$\boxed{P/T = \frac{6 \times \sqrt{\sigma^2_{MS}}}{USL - LSL}}$$

  - This fraction is usually expressed as a percentage
  - Best case P/T < 10% -- **Acceptable P/T < 30%**



P/T is the most common gage metric.

Measurement System Metrics – P/TV

- Precision to Total Variance Ratio
  - Addresses the fraction of the total variance taken up by the gage variance
  - Best Case < 10%   Acceptable < 30%

$$P/TV = \frac{6\times\sqrt{\sigma_{MS}^2}}{6\times\sqrt{\sigma_{total}^2}} = \frac{6\times\sigma_{MS}}{6\times\sigma_{total}} = \frac{\sigma_{MS}}{\sigma_{total}} \approx \frac{\sigma_{MS}}{\sigma_{historical}}$$

$$\%R\&R = \frac{P}{TV}\times 100\% = \frac{\sigma_{MS}}{\sigma_{historical}}\times 100\%$$

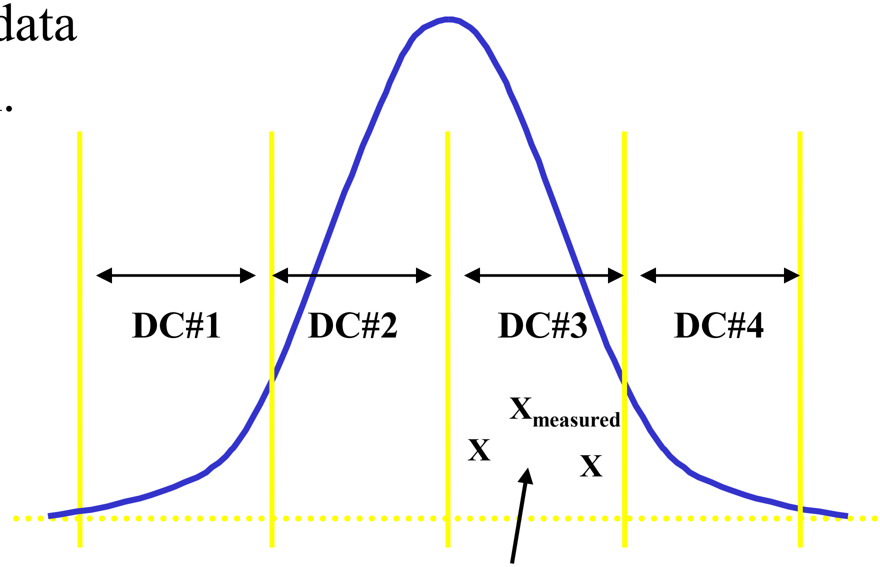
Note: Not always equal!

P/TV is best for improvement projects.

MS Metrics – Number of Distinct Categories

$$\#DistinctCategories = round_{down}\left(\frac{\sigma_{Parts}}{\sigma_{MS}} \times 1.41\right)$$

- Number of Distinct Categories is the number of distinct categories within the process data that the measurement system can discern.
- The number of distinct categories is a measure of the resolution
- The number of distinct categories is a function of the Repeatability & Reproducibility
- Acceptable: greater then equal to 4



Number of Distinct Categories is Resolution.

Gage Metric Summary

	$\frac{\sigma^2_{MS}}{\sigma^2_{Total}}$ or $\frac{\sigma^2_{MS}}{\sigma^2_{Hist}}$	$\frac{\sigma_{MS}}{\sigma_{total}}$ or $\frac{\sigma_{MS}}{\sigma_{hist}}$	$\frac{6 \times \sigma_{MS}}{USL - LSL}$	$1.41 \times \frac{\sigma_{Parts}}{\sigma_{MS}}$
	%Contribution (%TV)	P/TV (%R&R)	P/T (%Tolerance)	Distinct Categories
No Issues	< 1%	< 10%	< 10%	> 4
Marginally Acceptable	1 - 9%	10 - 30%	10 - 30%	3 - 4
Do Not Use	> 9%	> 30%	> 30%	< 3

How do your gages measure up?

Rules of Thumb–Acceptable Ranges

Analyzing Gage R&R Results

1. R&R less than 10%–Measurement System "acceptable"

2. R&R 10% to 30%–May be acceptable–make decision based on classification of Characteristic, Application, Customer Input, etc.

3. R&R over 30%–Not acceptable. Find problem, re-visit the Fishbone Diagram, remove Root Causes. Is there a better gage on the market, is it worth the additional cost?

Gauge R & R (Destructive testing)

Gage R&R Study (Nested) when each part is measured by only one operator, such as in destructive testing . In destructive testing, the measured characteristic is different after the measurement process than it was at the beginning. Crash testing is an example of destructive testing.

Three operators each measured five different parts twice, for a total of 30 measurements. Each part is unique to operator; no two operators measured the same part. You decide to conduct a gage R&R study (nested) to determine how much of your observed process variation is due to measurement system variation .

You need to use destructive testing, you must be able to assume that all parts within a single batch are identical enough to claim that they are the same part. If you are unable to make that assumption then part-to-part variation within a batch will mask the measurement system variation.

Attribute R&R – Terminology

- **Appraiser Score (%)** – the fraction of time the operator agrees with himself during an attribute R&R
- **Attribute Data** – qualitative (go / no go) data that can be tallied for recording and analysis
- **Attribute Measurement System** – a measurement system that compares each part to a standard and accepts the part if this standard is met

- **Operator Consistency** ***(Trial Match)***
  - % of times an operator repeats his observation in trial 2 as compared to trial 1
- **Mutual Consistency** ***(Operator Agreement)***
  - % of times both operators are in complete sync
- **Operator Efficiency** ***(True Match)***
  - % of times an operator has both his observations matched with true value
- **Measurement Efficiency** ***(True Agreement)***
  - % of times both operators are in complete sync with the true value

Attribute R&R – Method

- Setup
  - Select 30 parts from the process. 50% passers, 50% defects
  - If possible, select borderline or marginal good and bad samples
  - Select inspectors – fully trained and qualified
- Execution
  - Each inspector inspects the parts in random order to determine pass and fail. Each inspector repeats the inspection I
- Analysis
  - Enter the data into the spreadsheet AttributeR&R.xls to determine the effectiveness of the measurement system.
- Evaluation
  - Document the results.
  - Implement appropriate actions to fix the process if necessary
  - Rerun the study to verify the effectiveness of the fixes

AttributeR&R.xls

Worksheet for Discrete Data

- Data to be filled only in "YELLOW"cells

RR - Discrete Dat

GRR --- Discrete Data

Part Number	True Value	Operator 1				Operator 2				Operator Agreement (Yes / No)	True Agreement (Yes / No)
		Trial 1	Trial 2	Trial Match	True Match	Trial 1	Trial 2	Trial Match	True Match		
1				Yes	Yes			Yes	Yes	Yes	Yes
2				Yes	Yes			Yes	Yes	Yes	Yes
3				Yes	Yes			Yes	Yes	Yes	Yes
4				Yes	Yes			Yes	Yes	Yes	Yes
5				Yes	Yes			Yes	Yes	Yes	Yes
6				Yes	Yes			Yes	Yes	Yes	Yes
7				Yes	Yes			Yes	Yes	Yes	Yes
8				Yes	Yes			Yes	Yes	Yes	Yes
9				Yes	Yes			Yes	Yes	Yes	Yes
10				Yes	Yes			Yes	Yes	Yes	Yes
11				Yes	Yes			Yes	Yes	Yes	Yes
12				Yes	Yes			Yes	Yes	Yes	Yes
13				Yes	Yes			Yes	Yes	Yes	Yes
14				Yes	Yes			Yes	Yes	Yes	Yes
15				Yes	Yes			Yes	Yes	Yes	Yes

Operator Consistency	Op 1	Op 2
	100%	100%

Mutual Consistency	Overall
	100%

Operator Efficiency	Op 1	Op 2
	100%	100%

Measurement Efficiency	Overall
	100%

Example for Discrete Data

GRR --- Discrete Data

Part Number	True Value	Operator 1				Operator 2				Operator Agreement (Yes / No)	True Agreement (Yes / No)
		Trial 1	Trial 2	Trial Match	True Match	Trial 1	Trial 2	Trial Match	True Match		
1	Good	Good	Good	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes
2	Good	Good	Bad	No	No	Good	Bad	No	No	No	No
3	Good	Good	Bad	No	No	Good	Good	Yes	Yes	No	No
4	Bad	Good	Bad	No	No	Bad	Bad	Yes	Yes	No	No
5	Good	Bad	Bad	Yes	No	Bad	Bad	Yes	No	Yes	No
6	Bad	Bad	Bad	Yes	Yes	Bad	Bad	Yes	Yes	Yes	Yes
7	Good	Good	Good	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes
8	Bad	Bad	Bad	Yes	Yes	Bad	Bad	Yes	Yes	Yes	Yes
9	Bad	Bad	Bad	Yes	Yes	Bad	Bad	Yes	Yes	Yes	Yes
10	Bad	Good	Good	Yes	No	Bad	Bad	Yes	Yes	No	No
11	Bad	Bad	Bad	Yes	Yes	Bad	Bad	Yes	Yes	Yes	Yes
12	Good	Good	Good	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes
13	Good	Good	Good	Yes	Yes	Good	Bad	No	No	No	No
14	Good	Good	Good	Yes	Yes	Bad	Bad	Yes	No	No	No
15	Bad	Bad	Bad	Yes	Yes	Bad	Bad	Yes	Yes	Yes	Yes

Operator Consistency	Op 1	Op 2
	80%	87%

Mutual Consistency	Overall
	60%

Operator Efficiency	Op 1	Op 2
	67%	73%

Measurement Efficiency	Overall
	53%

Attribute Measurement System

- An attribute measurement system compares each part to a standard and either accepts or rejects the part.
- The screen effectiveness is the ability of the attribute measurement system to properly discriminate good from bad.
- Screen effectiveness of 100% is desirable.

Conducting Attribute Gauge R&R

- 1. Select a minimum of 30 parts from the process. These parts should represent the full spectrum of process variation (good parts, defective parts, borderline parts).
- 2. An "expert" inspector performs an evaluation of each part, classifying it as "Good" or "Not Good."
- 3. Independently and in a random order, each of 2 or 3 operators should assess the parts as "Good" or "Not Good."
- 4. Calculate effectiveness scores.

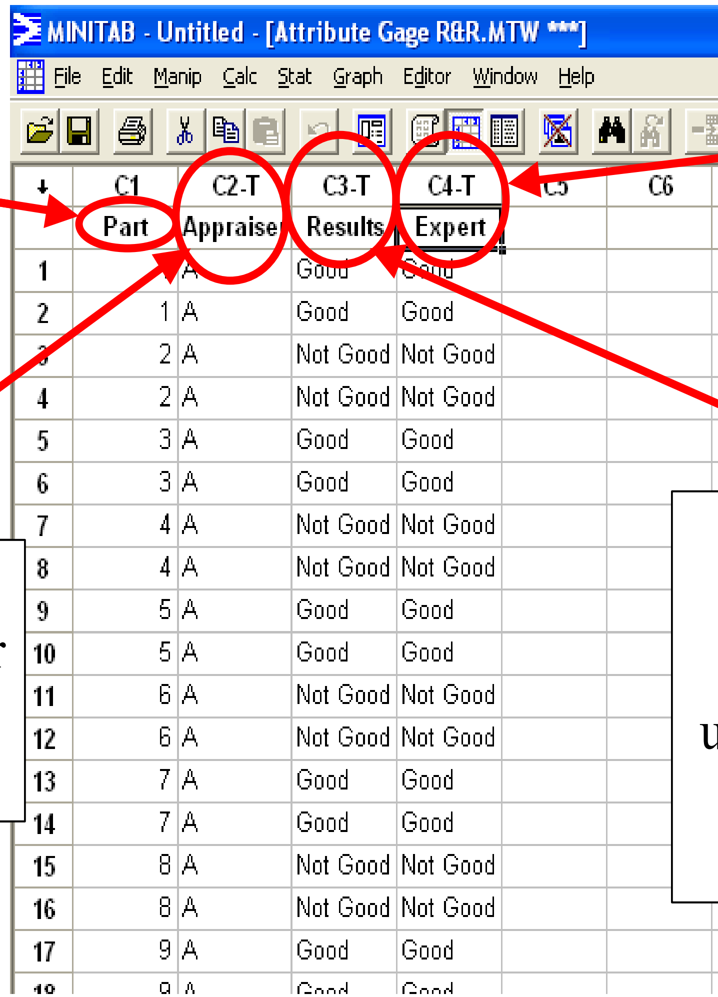
Attribute Gauge R&R

Minitab Data Layout:

Open Worksheet: Attribute Gage R&R

Column containing parts being assessed

Text column containing expert assessment (can use words or numbers but must be consistent)

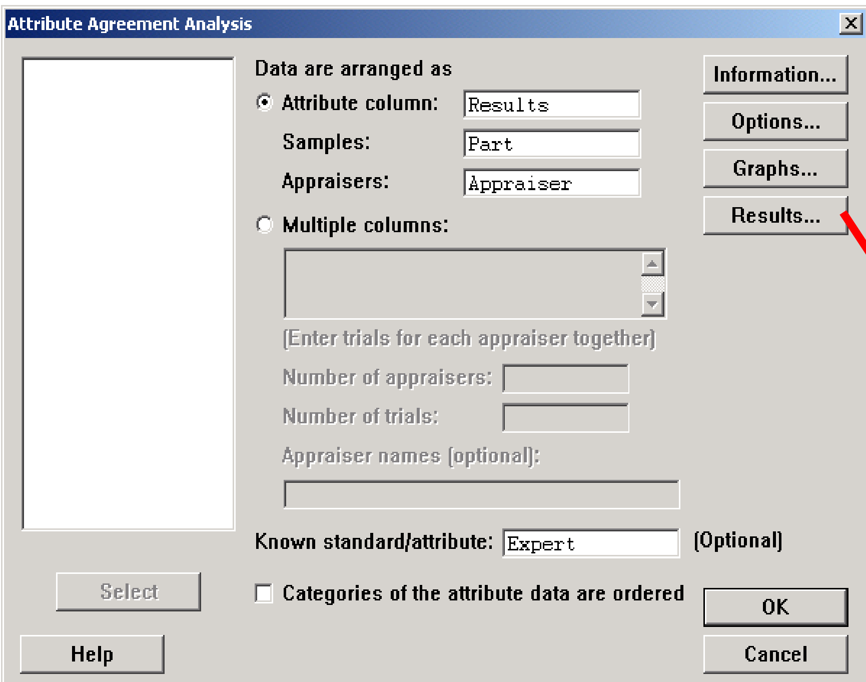


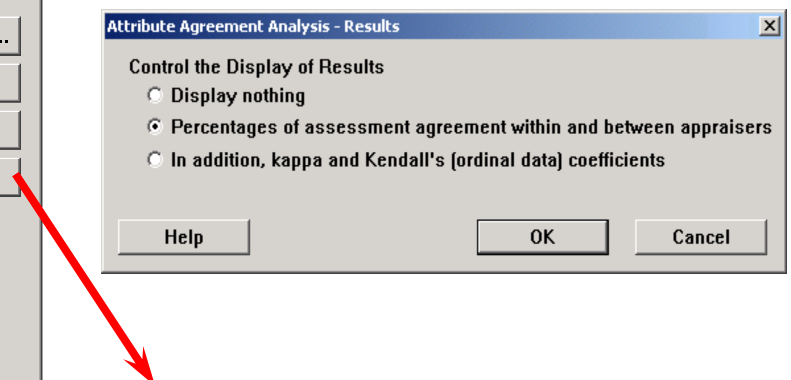
↓	C1	C2-T	C3-T	C4-T	C5	C6
	Part	Appraiser	Results	Expert		
1	[illegible]	A	Good	Good		
2	1	A	Good	Good		
3	2	A	Not Good	Not Good		
4	2	A	Not Good	Not Good		
5	3	A	Good	Good		
6	3	A	Good	Good		
7	4	A	Not Good	Not Good		
8	4	A	Not Good	Not Good		
9	5	A	Good	Good		
10	5	A	Good	Good		
11	6	A	Not Good	Not Good		
12	6	A	Not Good	Not Good		
13	7	A	Good	Good		
14	7	A	Good	Good		
15	8	A	Not Good	Not Good		
16	8	A	Not Good	Not Good		
17	9	A	Good	Good		
18	9	A	Good	Good		

Text column containing operator performing measurements

Text column containing results of measurements (can use words or numbers but must be consistent)

Stat>Quality Tools>Attribute Agreement Analysis
Enter "Results" in Attribute Column, "Part" in Samples, "Appraiser" in Appraisers and "Expert" in Known standard/attribute
Click on "Results" button and select "Percentages…"





Attribute Gauge R&R - Results

Attribute Agreement Analysis

Within Appraiser

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
A	30	28	93.3	(77.9, 99.2)
B	30	30	100.0	(90.5, 100.0)
C	30	30	100.0	(90.5, 100.0)

Matched: Appraiser agrees with him/herself across trials.

Appraiser A was not consistent on two out of thirty parts inspected

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
A	30	28	93.3	(77.9, 99.2)
B	30	29	96.7	(82.8, 99.9)
C	30	29	96.7	(82.8, 99.9)

Matched: Appraiser's assessment across trials agrees with standard.

Appraiser A disagreed with expert on two parts, Appraiser B and C disagreed with expert on one part

Attribute Gauge R&R - Results

Assessment Disagreement

Appraiser	# Not Good/ Good	Percent (%)	# Good/ Not Good	Percent (%)	# Mixed	Percent (%)
A	0	0.0	0	0.0	2	6.7
B	1	6.7	0	0.0	0	0.0
C	1	6.7	0			

\# Not Good/Good: Assessments across trials = Not G

\# Good/Not Good: Assessments across trials = Good

\# Mixed: Assessments across trials are not identic

Appraiser B assessed one part as Not Good when the standard (expert) assessed it as Good

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent (%)	95.0% CI
30	26	86.7	(69.3, 96.2)

\# Matched: All appraisers' assessments agree with each other.

Appraiser A,B and C agreed on 26 out of 30 parts inspected

All Appraisers vs Standard

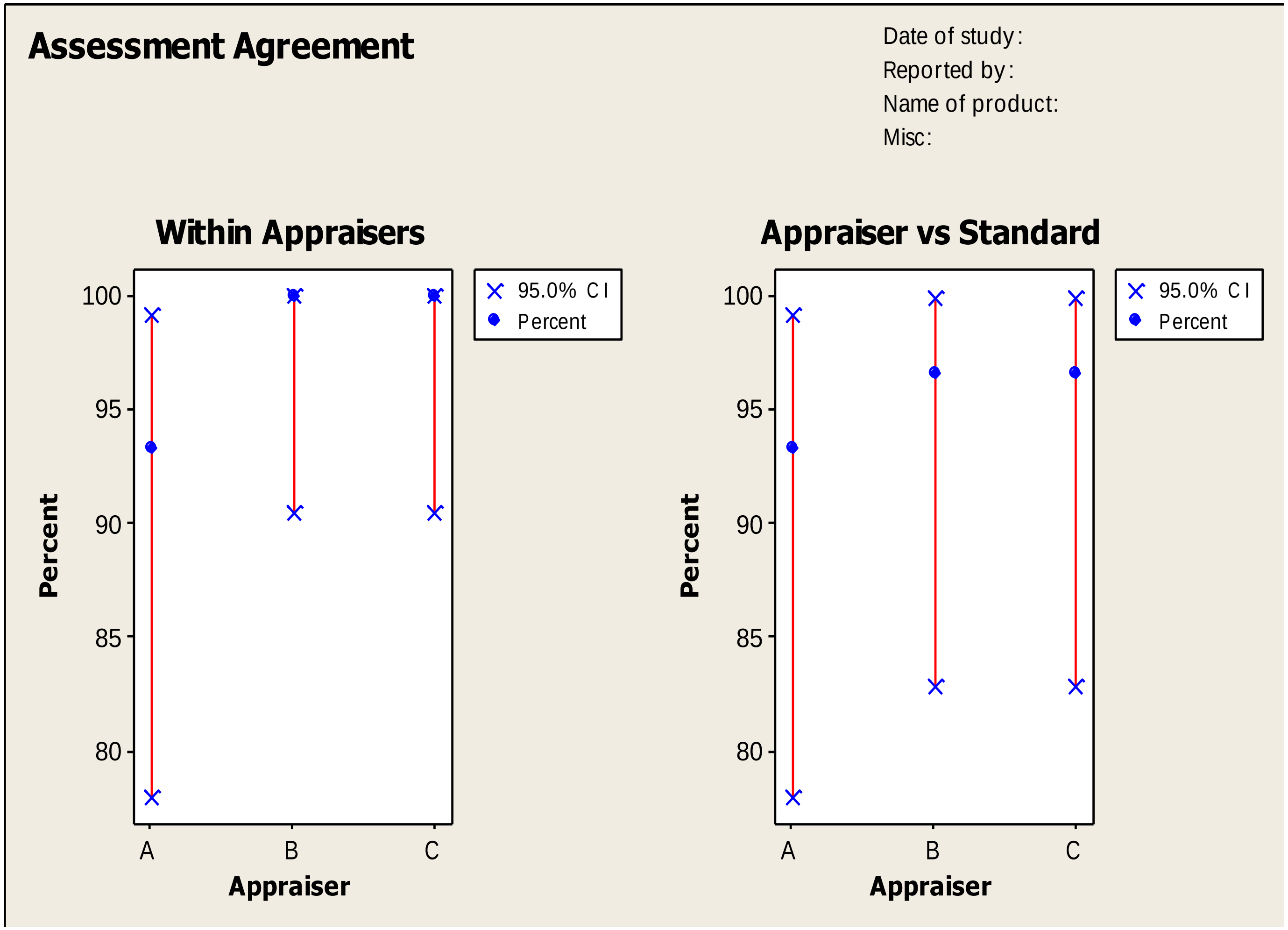
Assessment Agreement

# Inspected	# Matched	Percent (%)	95.0% CI
30	26	86.7	(69.3, 96.2)

\# Matched: All appraisers' assessments agree with standard.

Appraiser A,B and C all agreed with the standard on 26 out of 30 parts inspected

Attribute Gauge R&R - Results



Minitab Exercise

An educational testing company is training five new appraisers for the written portion of the twelfth-grade standardized essay test. The appraisers' ability to rate essays consistent with standards needs to be assessed. Each appraiser rated fifteen essays on a five-point scale (-2, -1, 0, 1, 2).

Attribute Gauge R&R - Results

- The target effectiveness is always 100%

- Possible Corrective Actions include:
  - Operator Training
  - Clarification of Standards
  - Simplification of Standards
  - Conversion to Variable Data

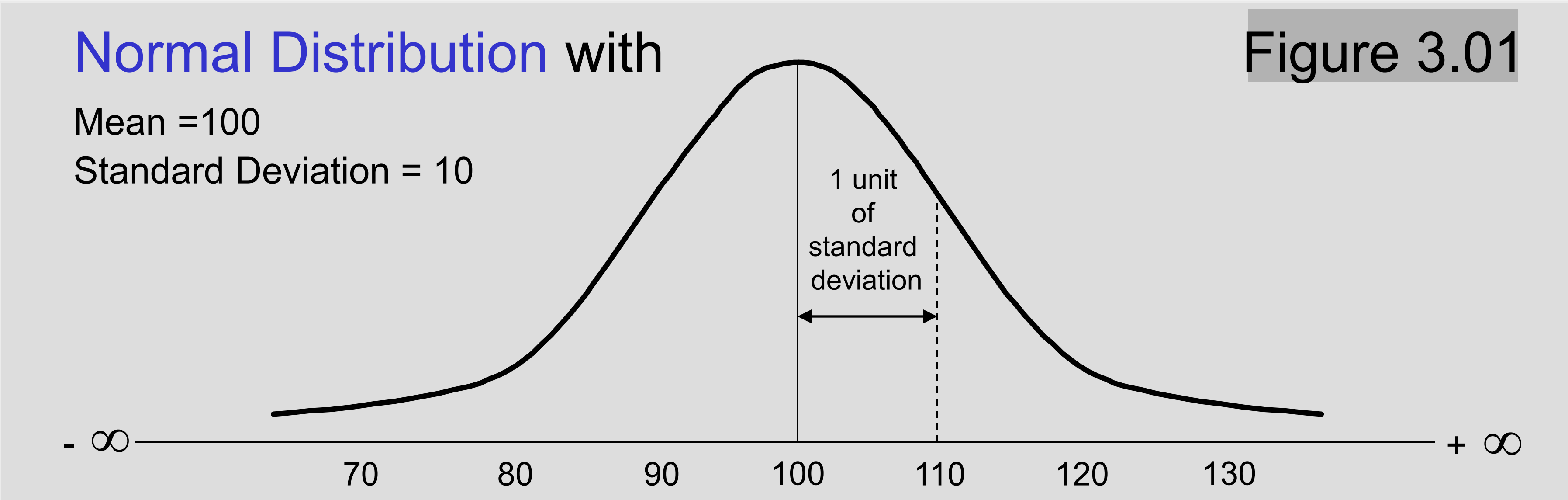
3.0 Normal Distribution

Introduction to Normal distribution

- Developed by astronomer *Karl Gauss*
- Most prominently used distribution in statistics
- Applicability to many situations where given the population knowledge, we need to predict

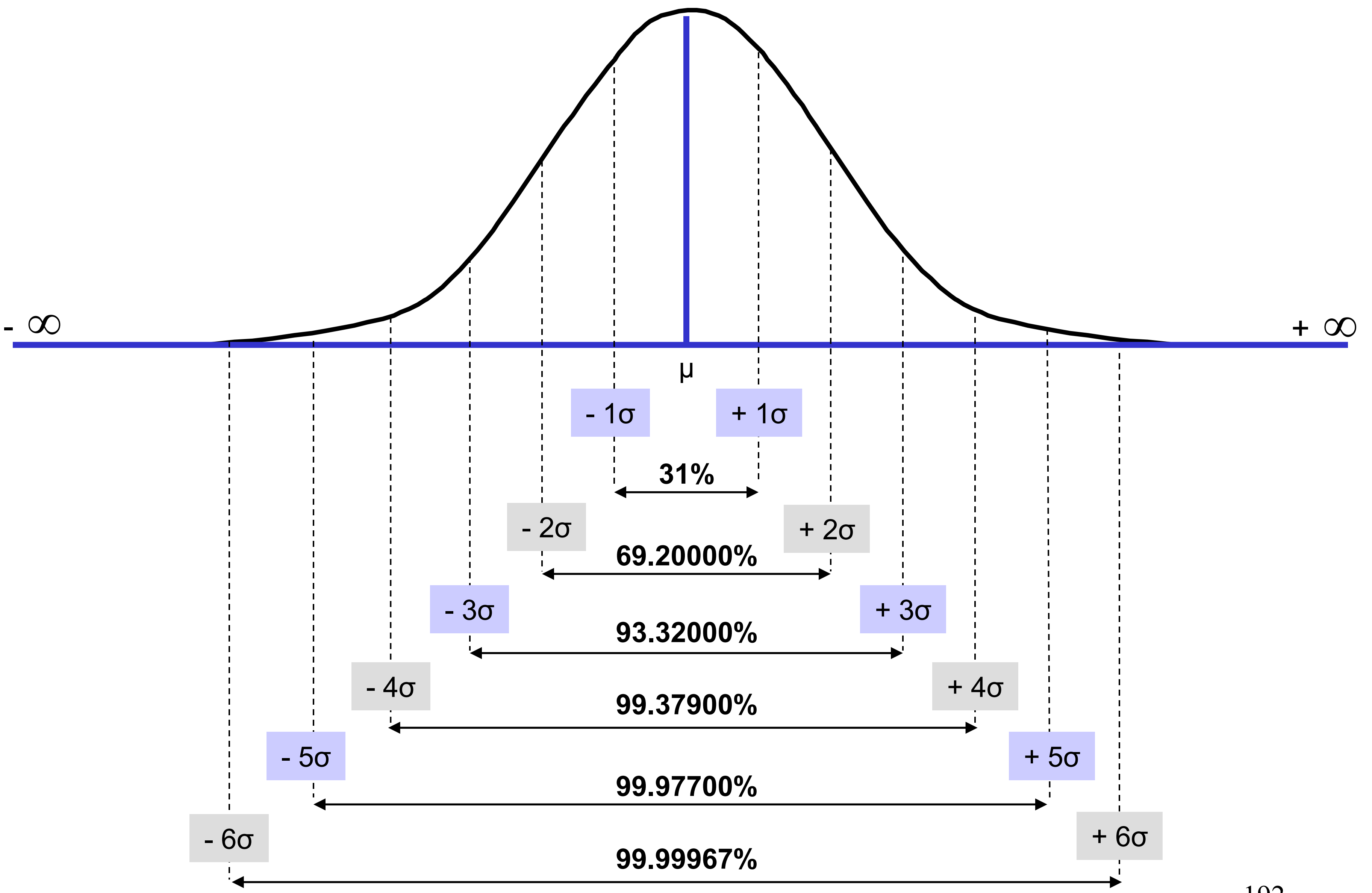
  the sample behavior
- It comes close to fitting the actual frequency distribution of many phenomena
  - Human characteristics such as weights, heights & IQ's
  - Physical process outputs such as yields

Introduction to Normal Distribution



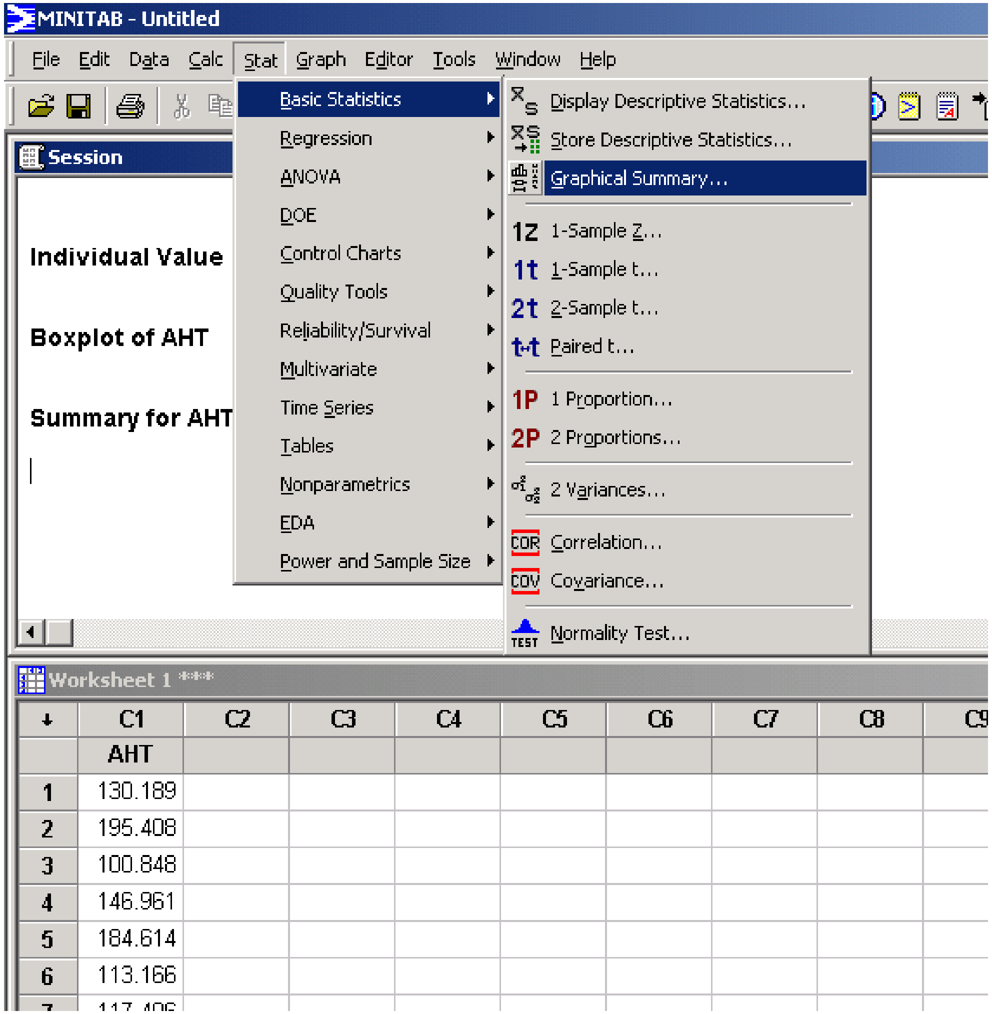
- It‟s a Probability Distribution, illustrated as N (μ, σ)
- Simply put, a probability distribution is a *theoretical* frequency distribution
- Higher frequency of values around the mean & lesser & lesser at values away from mean
- Continuous & symmetrical
- Tails asymptotic to X-axis
- Bell shaped
- Total area under the Normal curve = 1

Introduction to Normal Distribution



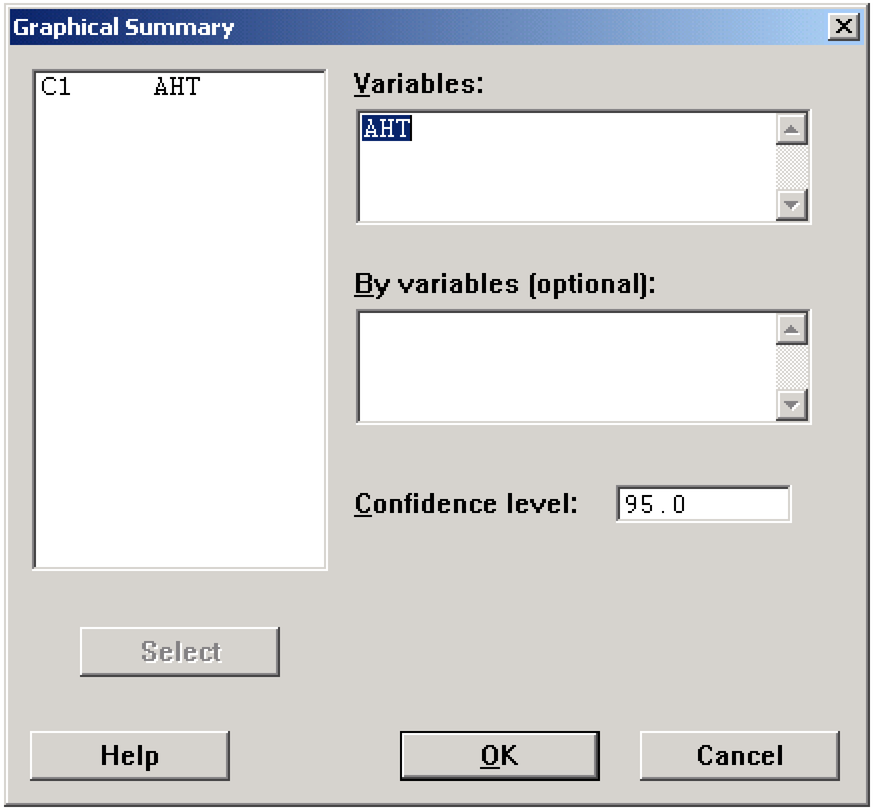
Normality

•We use Descriptive Statistics to test for Normality
•Paste your Y data into Minitab
•Now click on **Stat>Basic Statistics>Graphical Summary**



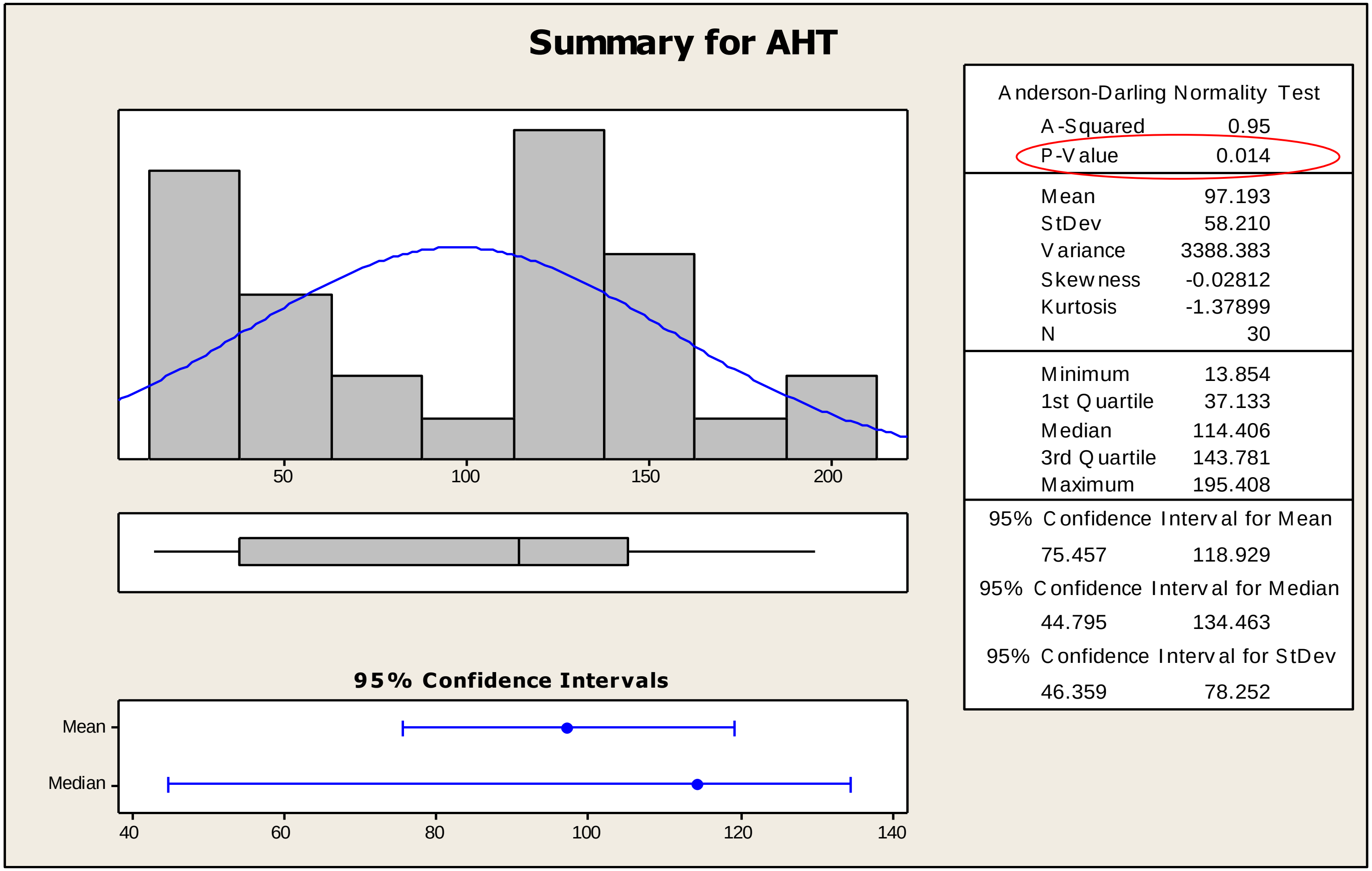
Normality

•In the „Variables"box select the column with the project Y data
•Click on OK



Normality

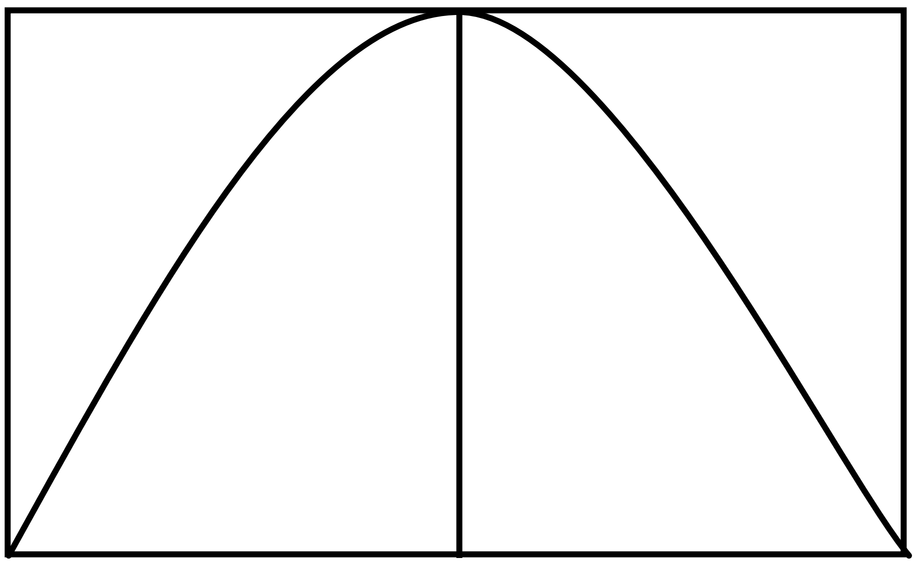
•Look for the p value. If it is greater than 0.05, your data is Normal, else Non Normal
•Also look at the shape to check for skewness and modality



Normality

If a data set is normal, it means that

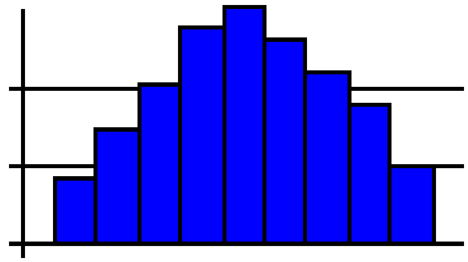
1. The area to the right of the curve is the same as the area to the left of the curve
2. Mean equals Median equals Mode
3. The P-value is greater than 0.05.
4. The ends run parallel to the X Axis



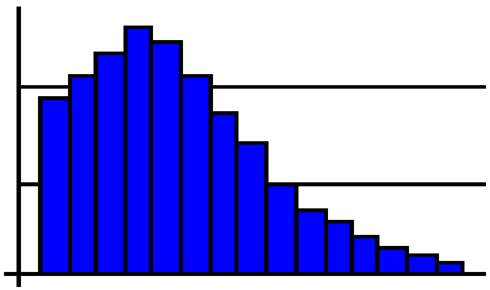
Shape

Distributions you could encounter

The *standard normal distribution*

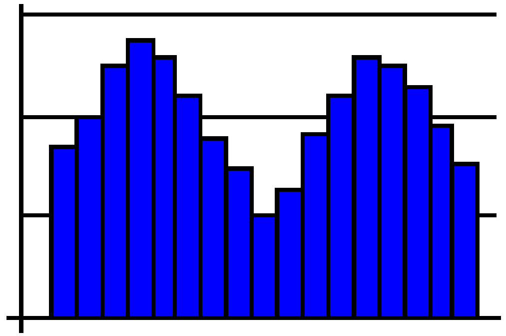


A *skewed distribution*, with one tail longer than the other. Data can be Right (positively) skewed or Left (negatively) skewed

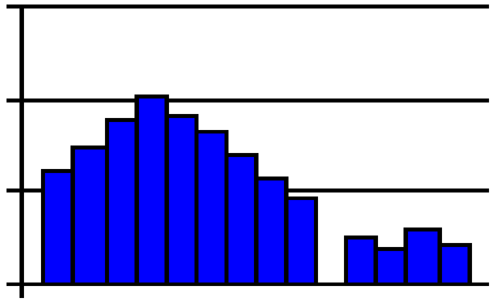


Shape

A double-peaked curve often means that the data actually reflects two distinct processes with different centers. You will need to re look at your data and check out on different processes / segmentation factors you might have missed out on. Data can be ***Unimodal, Bimodal, Trimodal or Multimodal***

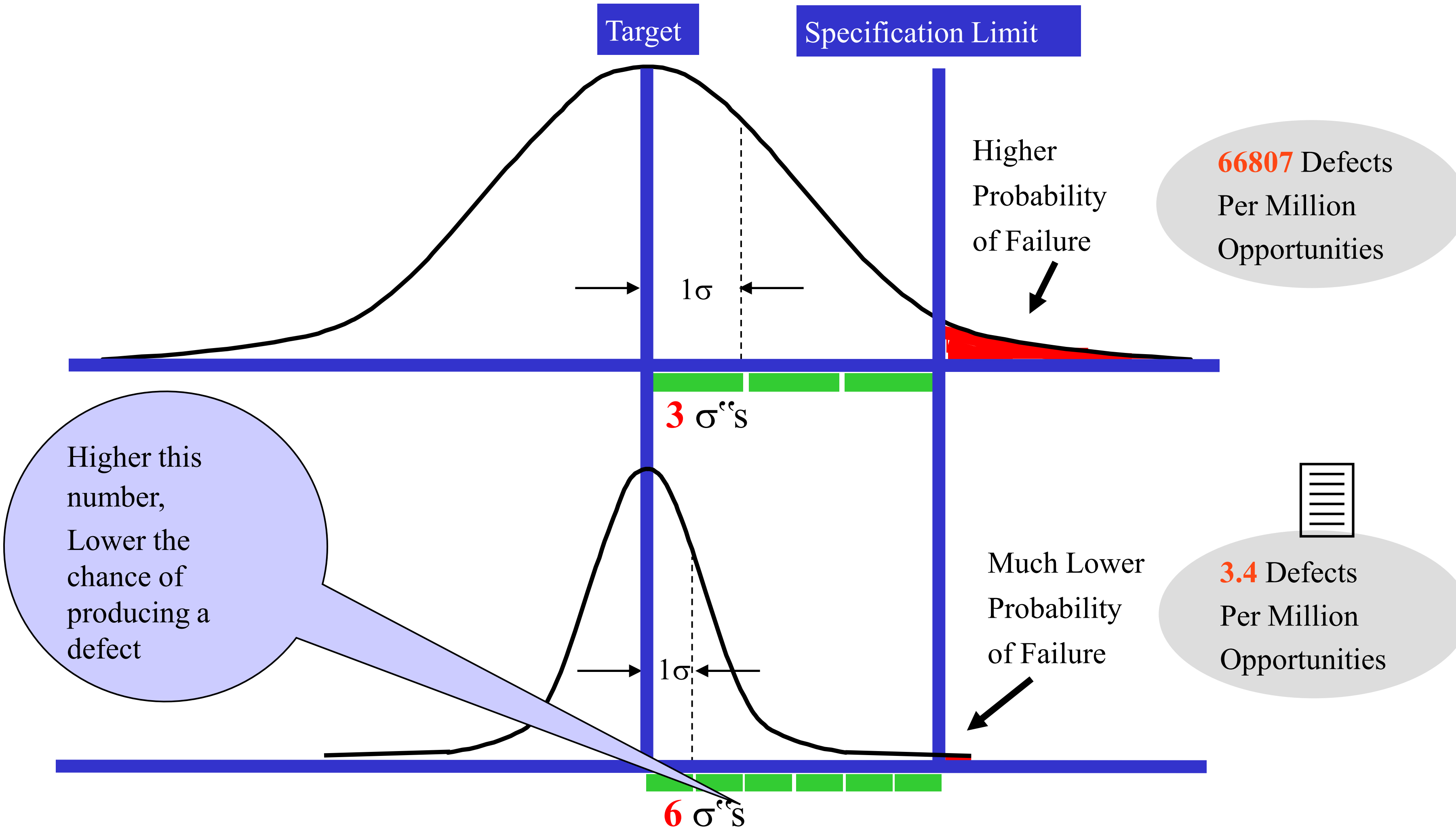


Outliers in a histogram – bars that are removed from the others by at least the width of one bar – sometimes indicate that perhaps a separate process is included, but one that doesn't happen all the time.

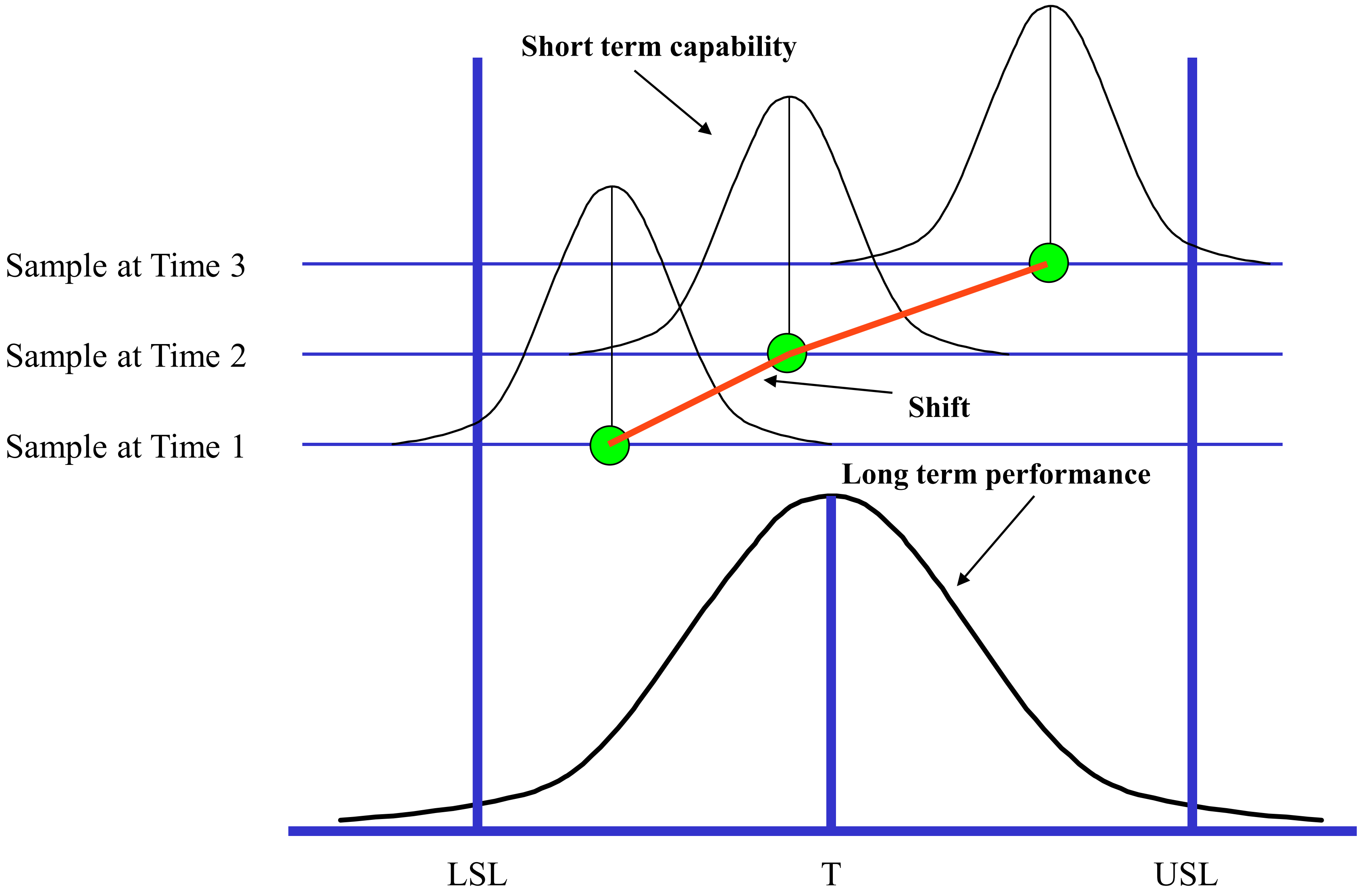


3.22 Process Sigma Multiple for Continuous Data

What is A Six Sigma Process?



Concept of Process Shift



Key Concepts

- Short term capability (Z_{ST})
  - It is the <u>capability or the potential performance</u> of the process, in control at any point of time
- Long term performance (Z_{LT})
  - It is the actual performance of the process over time
- Subgroups
  - Several small-sized samples collected consecutively, each sample forms a sub-group
    - Sub-groups are chosen so that data points are likely to be identical within subgroup, but different between subgroups
- Process shift ($Z_{ST} - Z_{LT}$)
  - It reflects how well a process is controlled, usually a factor of 1.5 is used

Concept of Process Shift

- Over time, a typical process will shift by approximately 1.5 standard deviations
- In other words, long term variation is typically 1.5 standard deviations more than the short term variation
- This difference is called the Sigma shift, which is an indicator of process control
- This shift could be due to different operators, raw material, wear & tear, time, etc.
- Standard deviation of the sample is called as the long term deviation.
- DPMO is always calculated on the long term standard deviation
- Discrete data Z values as studied in the previous session have been adjusted for shift

ZST, ZLT & DPMO

- DPMO indicates long-term performance (Z_{LT})
- Long term performance adjusted by a factor of 1.5 gives short term capability (Z_{ST})
- Short term capability is the *sigma multiple* of the process ($Z_{ST} = Z_{LT} + 1.5$)

DPMO	Z_{LT}	Z_{ST}
> = 500000	0.0	1.5
450000	0.1	1.6
400000	0.3	1.8
350000	0.4	1.9
300000	0.5	2.0
250000	0.7	2.2
200000	0.8	2.3
150000	1.0	2.5
100000	1.3	2.8
50000	1.6	3.1
40000	1.8	3.3
35000	1.8	3.3
30000	1.9	3.4
25000	2.0	3.5
20000	2.1	3.6
15000	2.2	3.7
12000	2.3	3.8

DPMO	Z_{LT}	Z_{ST}
10000	2.3	3.8
9000	2.4	3.9
8000	2.4	3.9
5000	2.6	4.1
3500	2.7	4.2
1500	3.0	4.5
1000	3.1	4.6
500	3.3	4.8
483	3.3	4.8
233	3.5	5.0
108	3.7	5.2
48	3.9	5.4
21	4.1	5.6
8	4.3	5.8
5	4.4	5.9
3.4	4.5	6.0
0.4	5.1	6.6

Process Variations

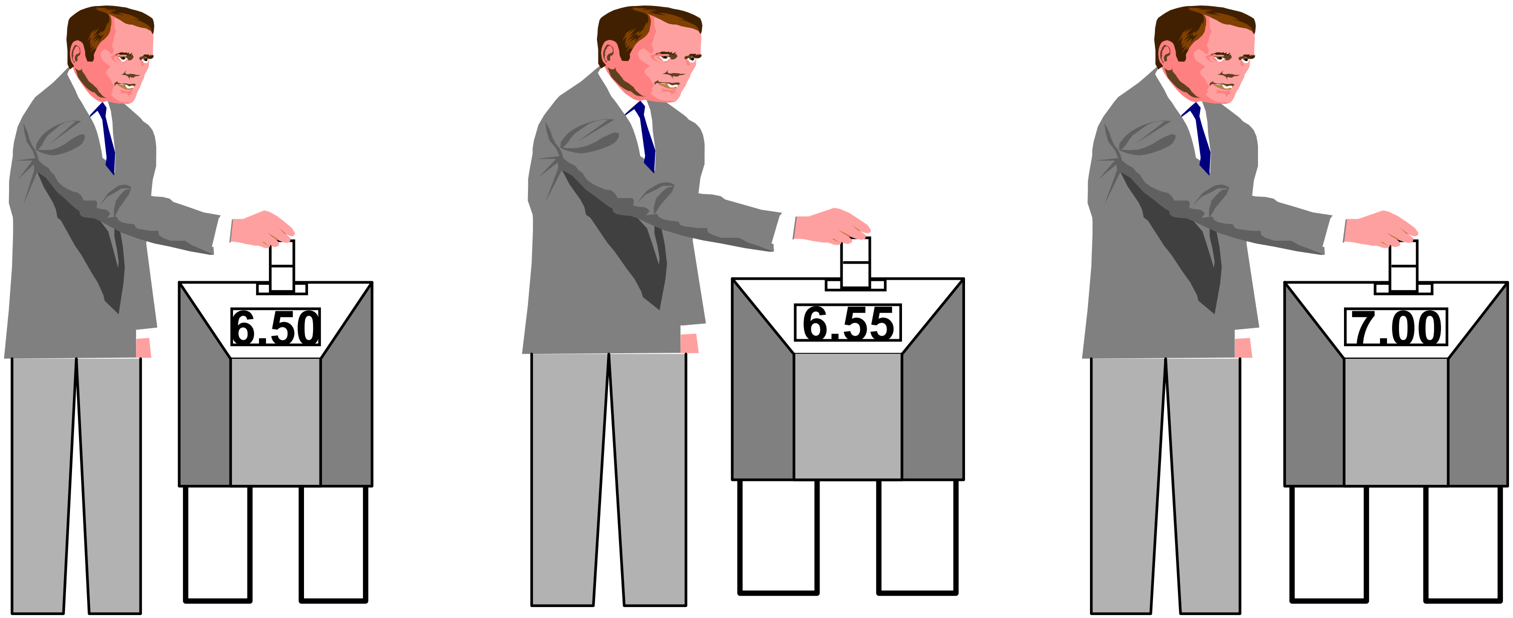
Common Cause	Special Cause
White Noise	Black Noise
Un-assignable Cause	Assignable Cause
Random	Systematic

WHAT IS VARIATION ?

- **No two things in nature are alike.**
- **This is also true for manufactured products.**
- **This dissimilarity between two products for the same characteristic is called variation.**
- **The variation may be or can be made to be so small so as to make the product SEEM similar.**
- **When we say that 2 things are similar we actually mean that it is not possible to measure the variation present within the accuracy of the existing measuring equipment.**
- **Variation between 2 products are compared for SIMILAR features or characteristics.**

TYPES OF VARIATION

- **Variations among pieces at the same time**
- **Variations across time**



6.55 a.m. ± 5 minutes.

This man wants to reach his work place by 6.55 a.m.. But he can not do so, exactly at 6.55 a.m. daily. Sometimes he reaches earlier (but almost never before 6.50 a.m.). Sometimes he reaches later (but almost never after 7.00 a.m.).

WHY ?

THIS IS BECAUSE....

OF CERTAIN FACTORS WHICH

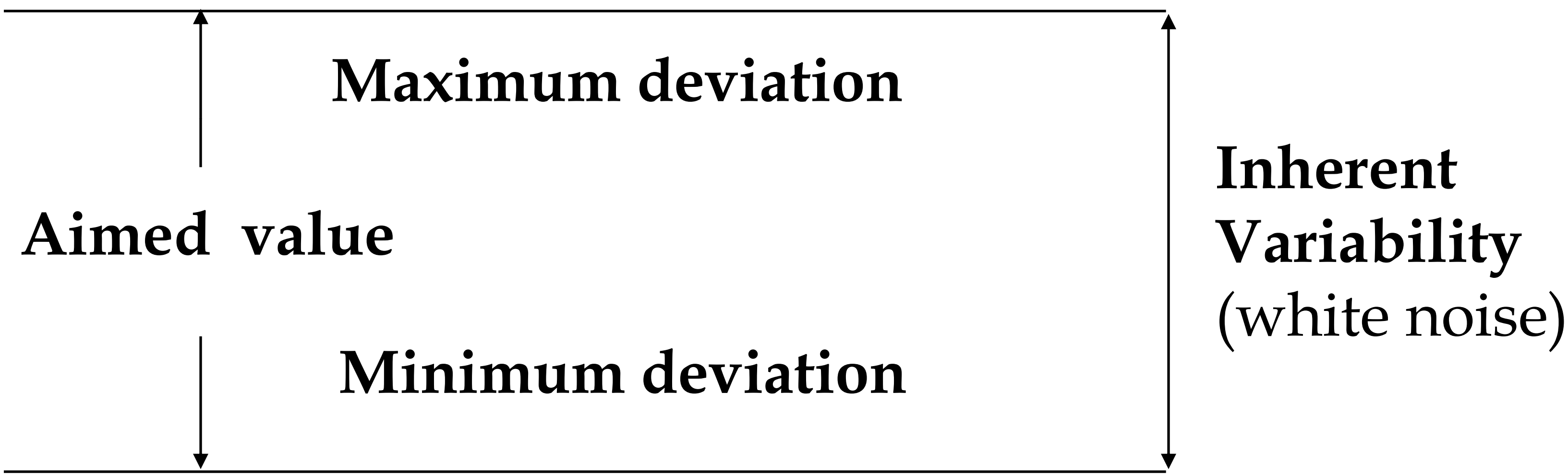
- Affect the time he takes
- He cannot control
- Vary randomly

e.g. The traffic you encounter under normal course of travel

THE VARIATION THAT OCCURS DUE TO THESE KIND OF FACTORS IS CALLED ***INHERENT VARIATION OR COMMON CAUSE VARIATION OR WHITE NOISE.***

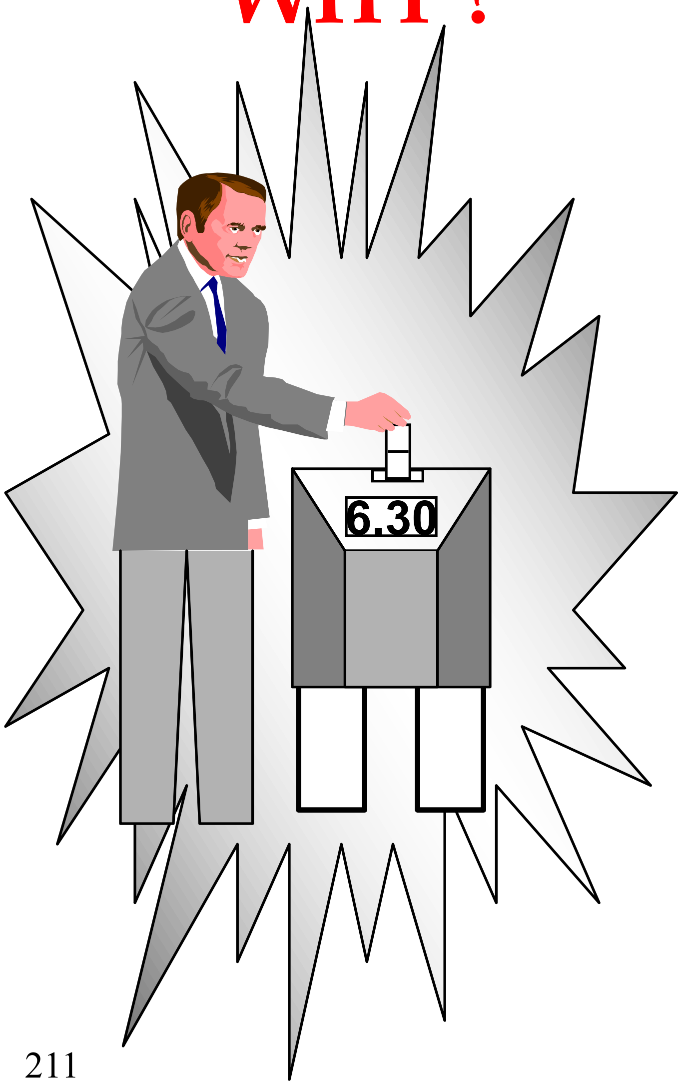
e.g.. m/c vibration,tool wear etc.

UNDER NORMAL SCHEME OF OPERATION



TODAY HE IS EARLY !

WHY ?



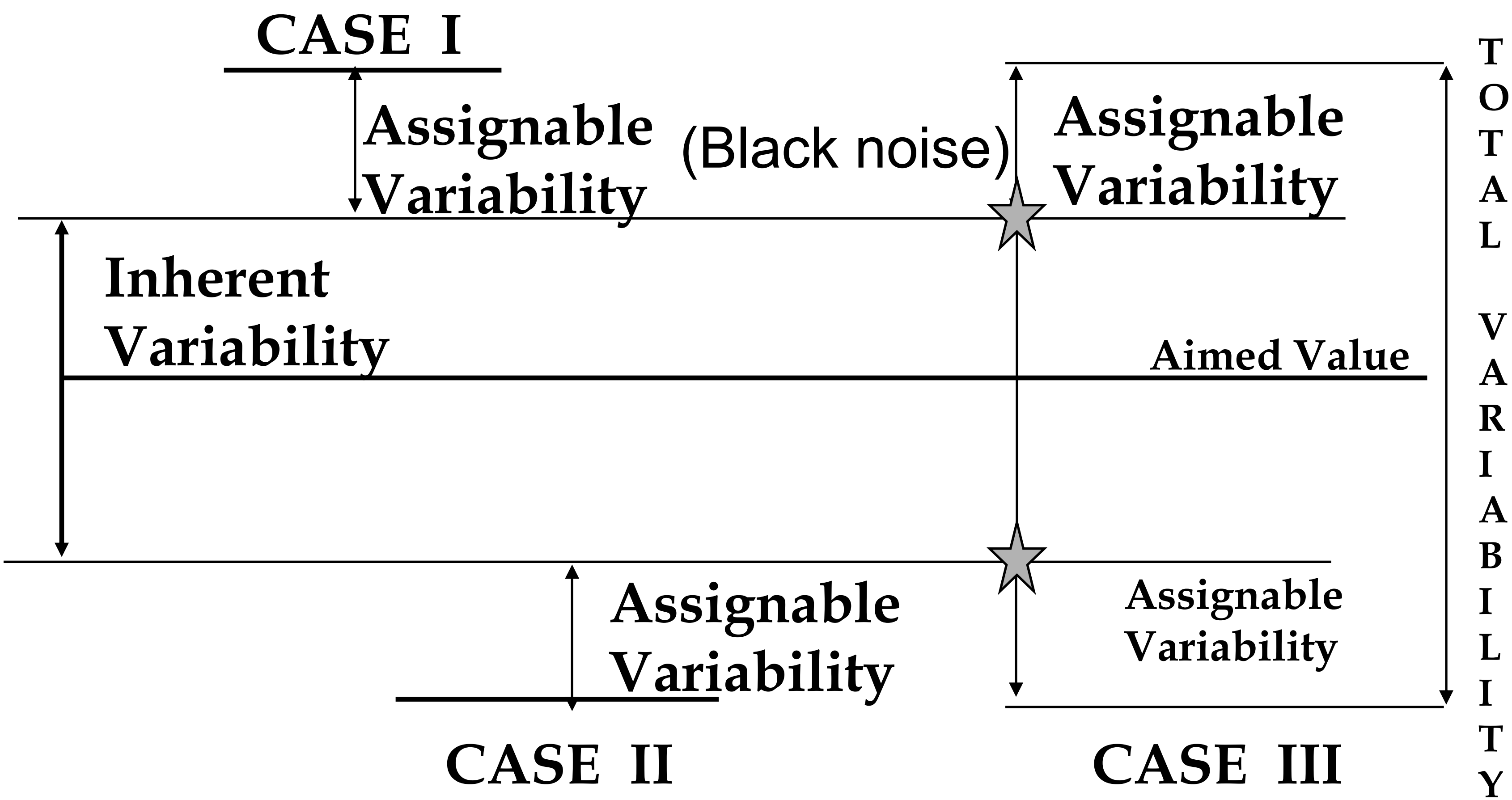
PROBABLY BECAUSE :

- His watch was running fast.
- He got a lift.
- His bus driver took a shortcut.
- He stayed over in the colony.
- He had some important work to be finished before 7.30.

These causes are characteristic of a specific circumstance and do not occur in the normal scheme of actions.

Variation due to these types of reasons is called **assignable** or **special cause variation** or **black noise**

GRAPHICAL DISPLAY OF VARIABILITIES

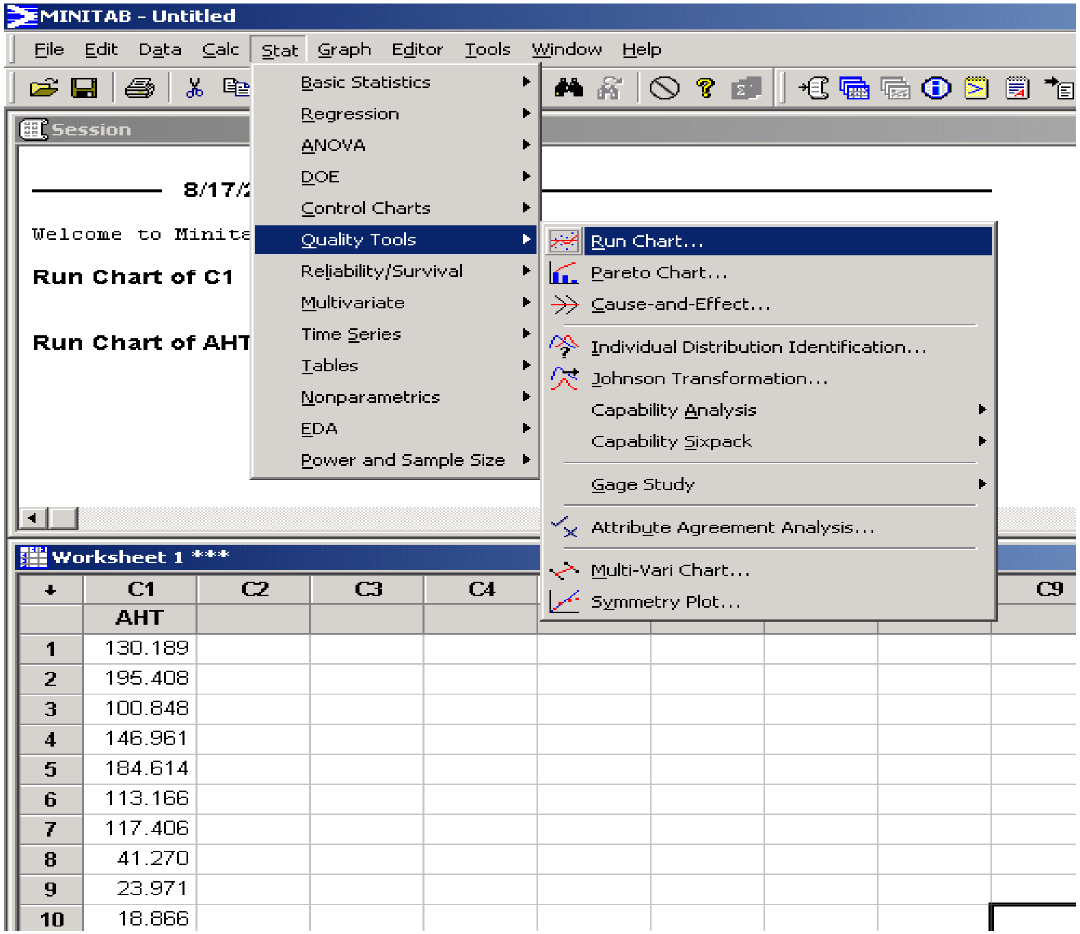


Stability

➢We use Run Charts to test for Stability.

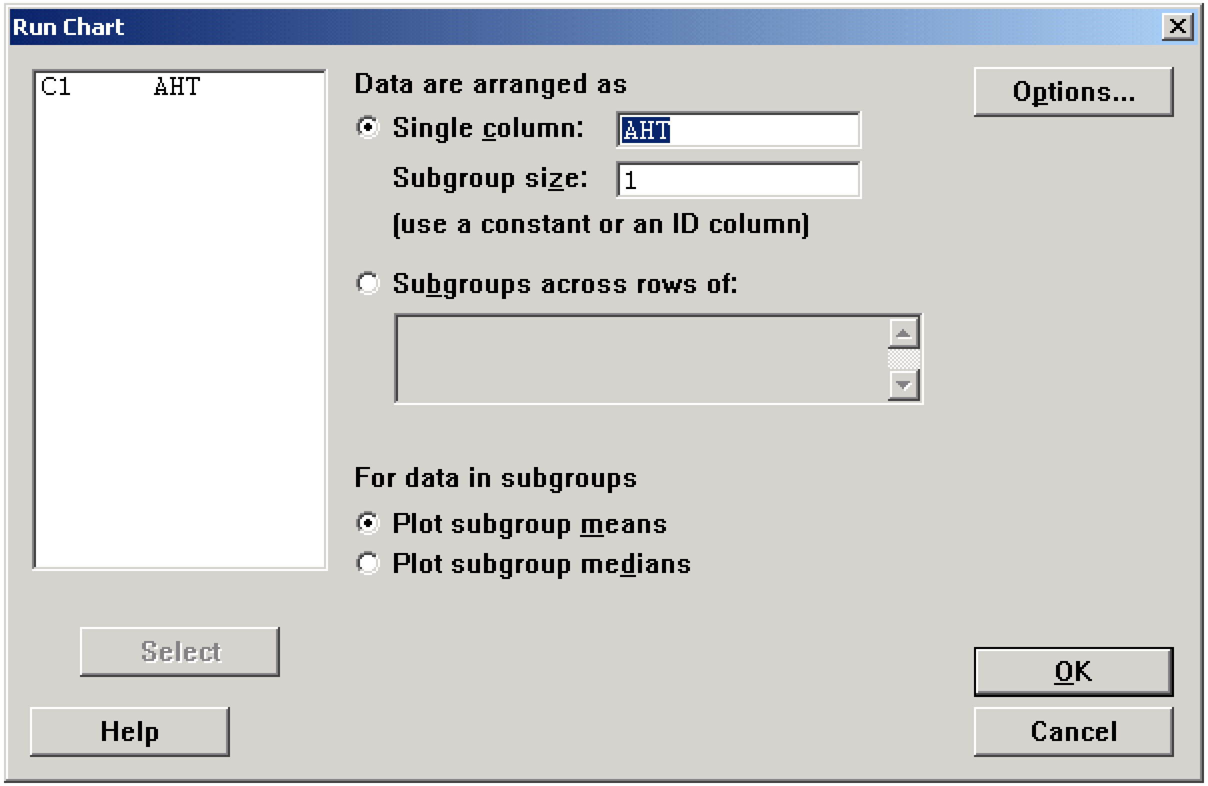
➢To check for stability (any special causes of variation)of your data, arrange your data in a time sequence in to Minitab

➢Now click on **Stat>Quality Tools>Run Chart**



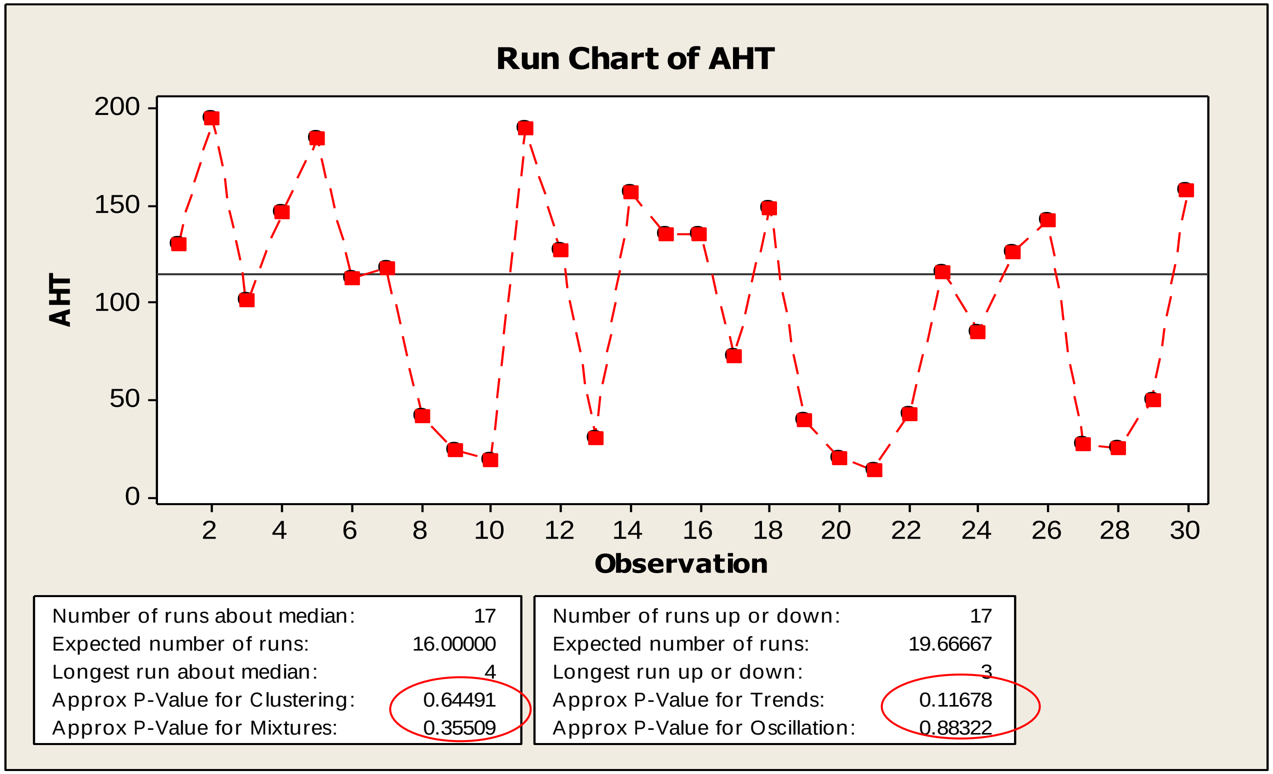
Stability

•In the "Single Column" section, select the project Y
•In the sub group size, either provide a constant number or an ID column (for instance date)
•Click on OK

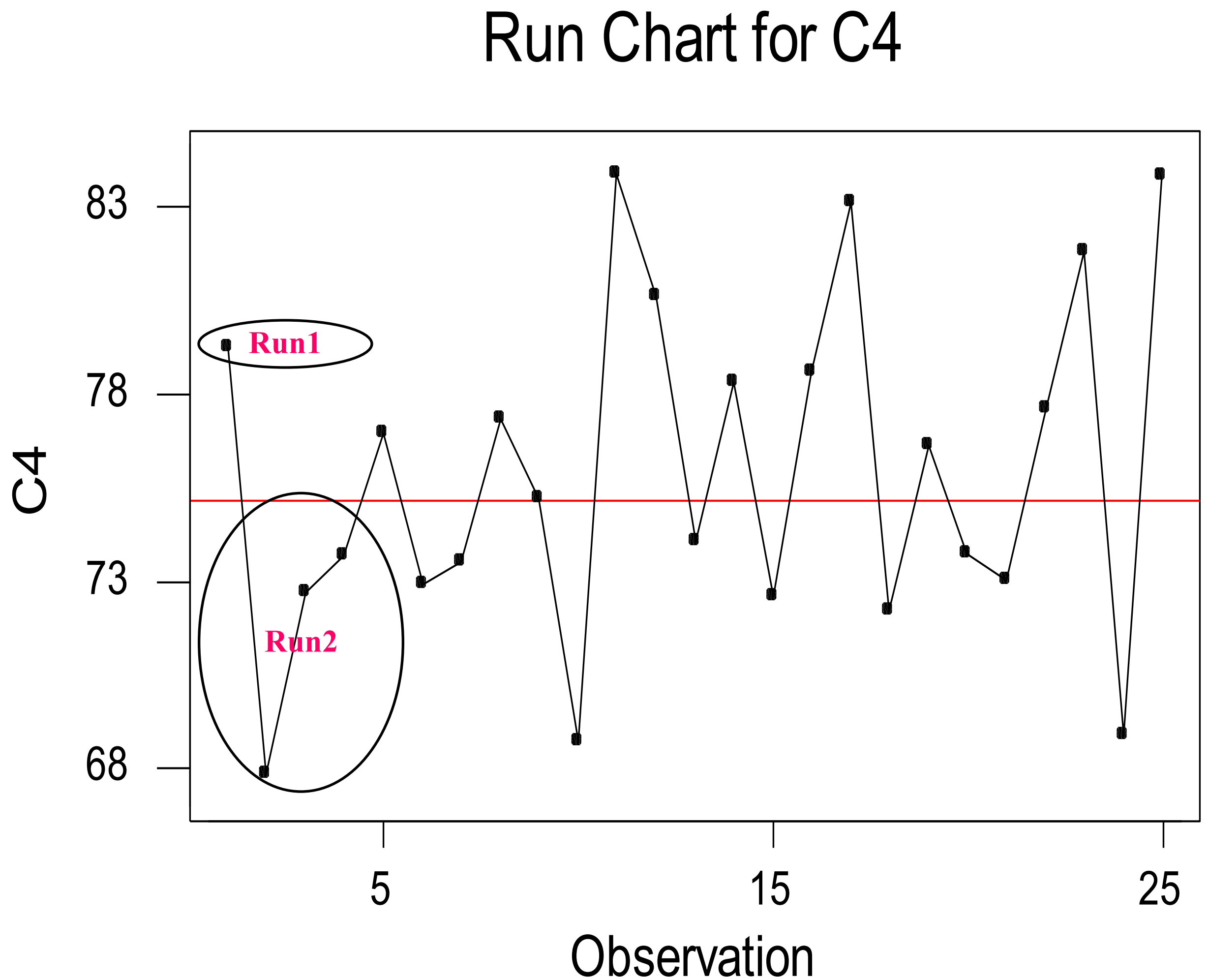


Stability

- ➢In the graphical output, you need to look for Clustering, Mixtures, Trends and Oscillations. If the p value for any of these is LESS than 0.05, your project Y displays special causes of variation
- ➢In case your data displays any special causes of variation, you need to isolate it and analyze it carefully before moving on to Hypothesis testing



Sample Run chart

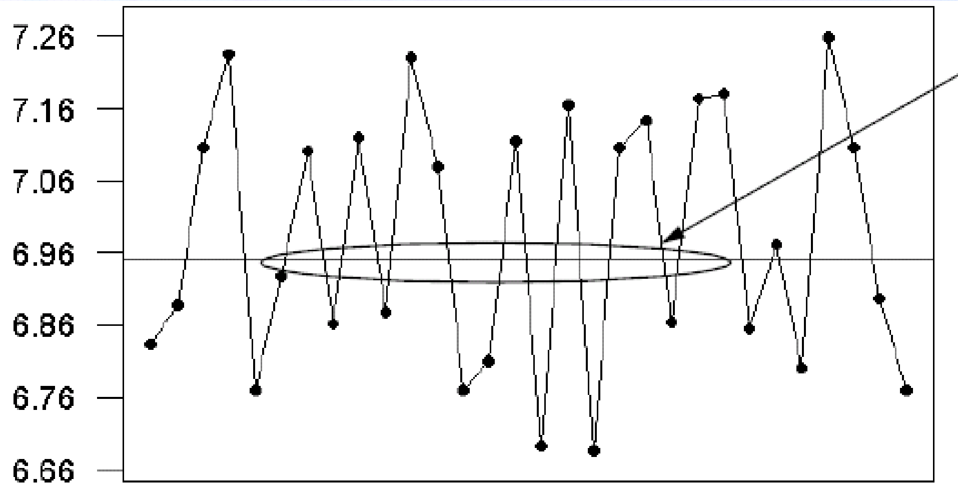


Number of runs about median:	17.0000	Number of runs up or down:	16.0000
Expected number of runs:	13.4800	Expected number of runs:	16.3333
Longest run about median:	3.0000	Longest run up or down:	3.0000
Approx P-Value for Clustering:	0.9252	Approx P-Value for Trends:	0.4348
Approx P-Value for Mixtures:	0.0748	Approx P-Value for Oscillation:	0.5652

Test for Randomness

Test for randomness	Condition	Indicates
number of runs about the median	more runs observed than expected	mixed data from two population
	fewer runs observed than expected	clustering of data
number of runs up or down	more runs observed than expected	oscillation—data varies up and down rapidly
	fewer runs observed than expected	trending of data

Mixture Pattern

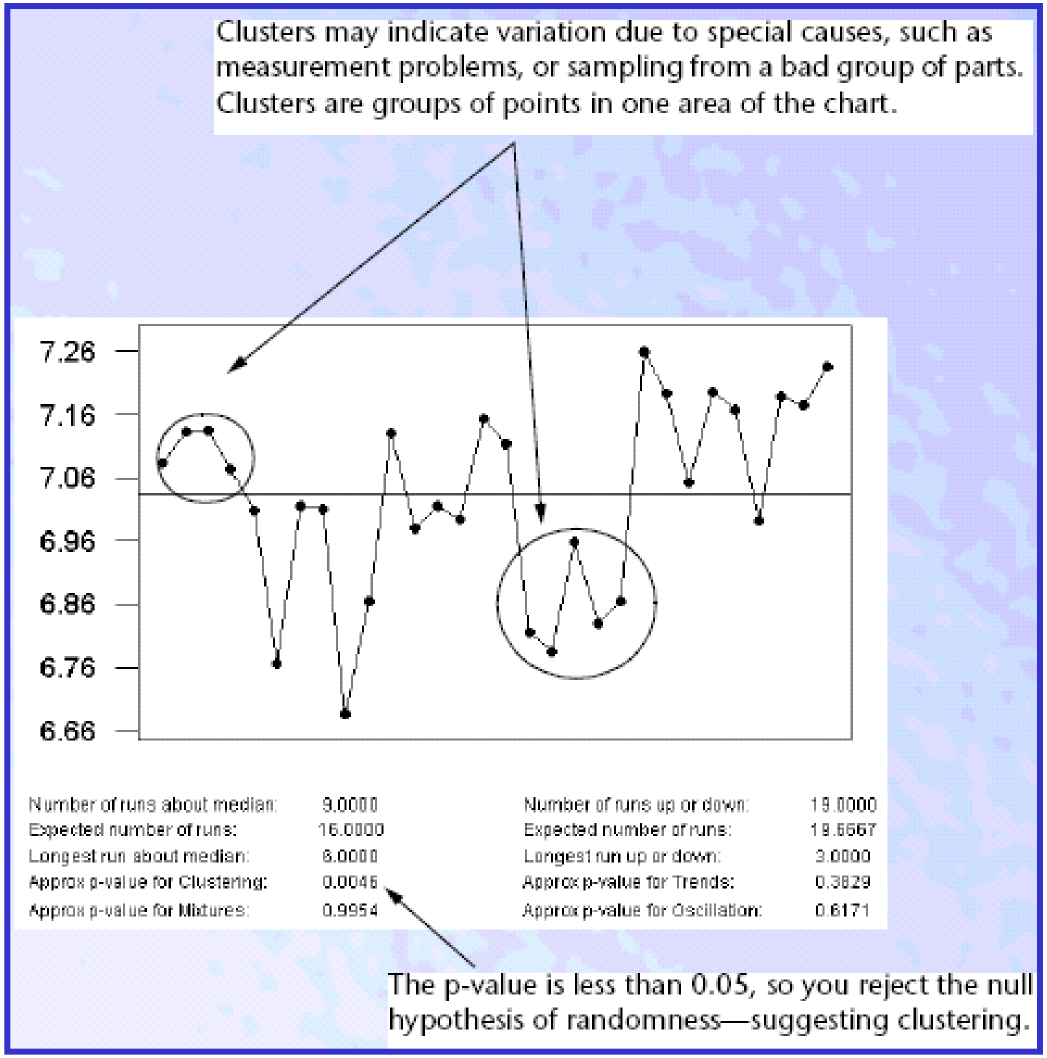


A mixture is characterized by an absence of points near the center line. Mixtures often indicate combined data from two populations, or two processes operating at different levels.

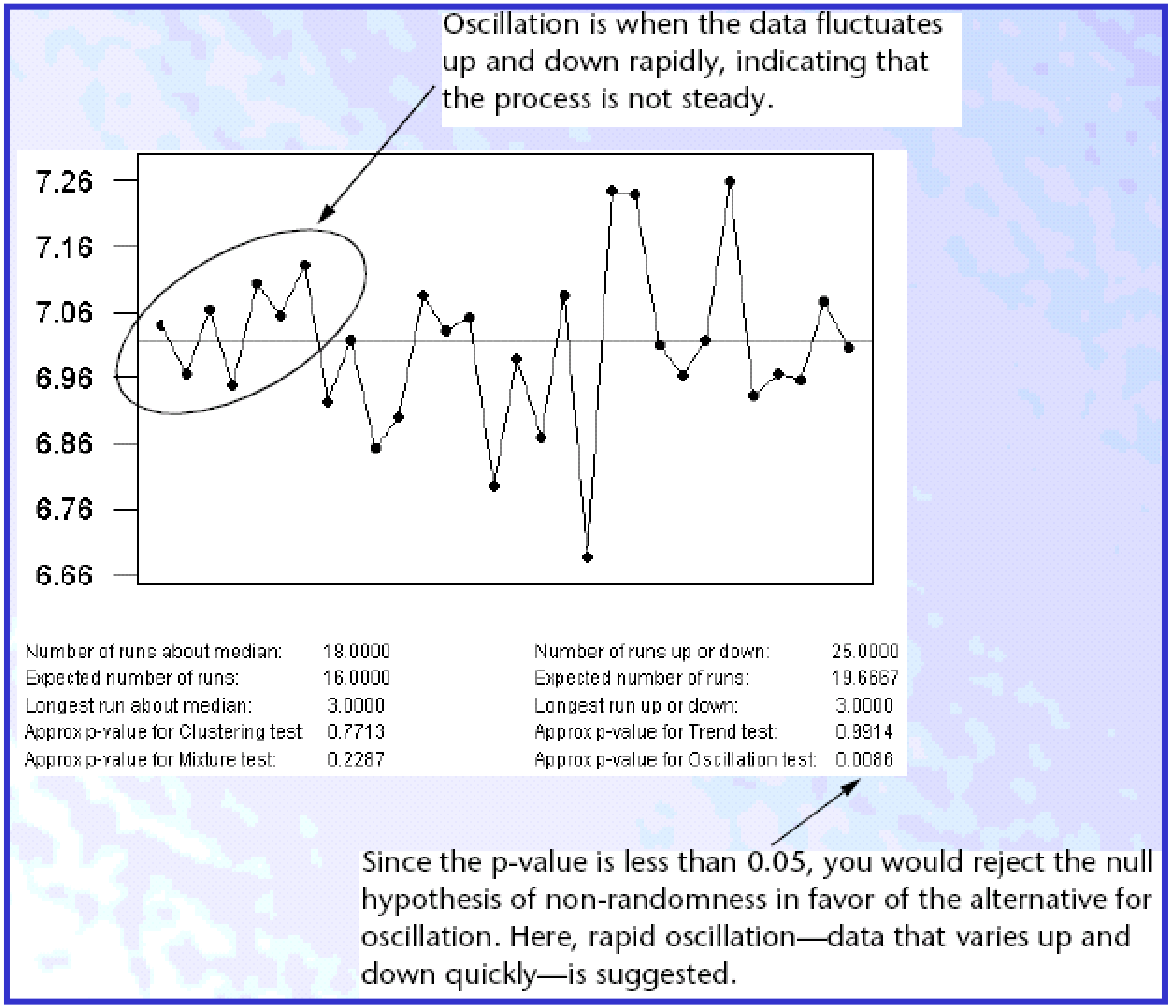
Number of runs about median:	21.0000	Number of runs up or down:	20.0000
Expected number of runs:	16.0000	Expected number of runs:	19.6667
Longest run about median:	2.0000	Longest run up or down:	4.0000
Approx p-value for Clustering:	0.9684	Approx p-value for Trends:	0.5592
Approx p-value for Mixtures:	0.0316	Approx p-value for Oscillation:	0.4408

The p-value for mixtures is less than 0.05, so you would reject the null hypothesis of randomness in favor of the alternative for mixtures—suggesting the data comes from different processes.

Cluster Pattern

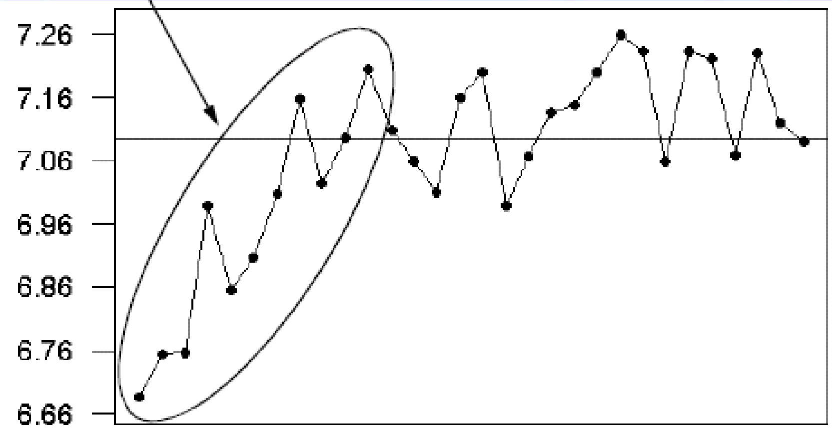


Oscillating Pattern



Trend Pattern

Trends are sustained and systematic sources of variation characterized by a group of points that drift either up or down. Trends may warn that a process is about to go out of control, and may be due to such factors as worn tools, a machine that will not hold a setting, or periodic rotation of operators.



Number of runs about median:	13.0000	Number of runs up or down:	14.0000
Expected number of runs:	16.0000	Expected number of runs:	19.6667
Longest run about median:	7.0000	Longest run up or down:	5.0000
Approx p-value for Clustering:	0.1325	Approx p-value for Trends:	0.0057
Approx p-value for Mixtures:	0.8675	Approx p-value for Oscillation:	0.9943

The p-value is less than 0.05, suggesting a trend in the data. In this case, the upward trend is circled and easily visible.

Process Variations

- Short term variation *(Common Cause)*
  - Variance inherent in the process (natural variation)
  - Also called <u>within sub-group variation</u>
  - Small number of samples, each sample collected in a short interval
  - Common cause variation is captured
  - Common causes can not be identified & corrected (process re-design would be needed)

- Long term variation *(Common + Special Cause)*
  - Added variation due to factors external to the usual process (abnormal variation)
  - Also called <u>overall variation</u> (sample standard deviation for all samples put together)
  - Large data collected over time
  - Special causes (different operators, raw material, wear & tear) lead to increase in variation
  - Special causes need to be identified & corrected for improvement
  - Long term variation is always greater than the short term variation

Calculating Process Variations

- Let‘s understand the concept of short & long term variations. Below is the data given on the pizza delivery time spread over 3 days. Each day‘s data can form a sub-group.

Pizza Delivery Time (Minutes)		
Day 1	**Day 2**	**Day 3**
48	50	49
49	48	48
48	36	39
53	50	49
58	50	34
50	62	33
46	45	57
50	47	48
49	51	47
47	44	39

Calculating Process Variations

Pizza Delivery Time (Minutes)					
Day 1	Average of day 1	Day 2	Average of day 2	Day 3	Average of day 3
48	49.8	50	48.3	49	44.3
49		48		48	
48		36		39	
53		50		49	
58		50		34	
50		62		33	
46		45		57	
50		47		48	
49		51		47	
47		44		39	

n_{sg1} = size of subgroup 1
= 10

	Day 1	Day 2	Day 3
Within Sub-group Variation	107.6	386.1	530.1
Grand Average	47.5		
Between Sub-group Variation	54.4	6.9	100.3

Total Variation within	1023.80	Overall Variation	1185.5
Total Variation Between	161.67		

Within sub-group variation for day 1 is Σ $(49.8\text{-}48)^2 + (49.8\text{-}49)^2 + (49.8\text{-}48)^2 + \ldots$ = 107.6

Between subgroup variation for day 1 is (Grand average – day 1 average)^2 * n_{sg1} = 54.4

Total variation within sub-groups is 107.6 + 386.1 + 530.1 = 1023.8

Total variation between subgroups is 54.4 + 6.9 + 100.3 = 161.67

Overall variation * is 1023.8 + 161.67 = 1185.5

* *Overall variation can also be calculated as per usual sample variance formula*

Calculating Process Variations

Within sub-group variation for day 1 is	$\Sigma\,(49.8-48)^2 + (49.8-49)^2 + (49.8-48)^2 + \ldots$	= 107.6
Between subgroup variation for day 1 is	(Grand average – day 1 average)^2 * n_{sg1}	= 54.4
Total variation within sub-groups is	107.6 + 386.1 + 530.1	= 1023.8
Total variation between subgroups is	54.4 + 6.9 + 100.3	= 161.67
Overall variation is	1023.8 + 161.67	= 1185.5

$$\text{Sigma short term } S_{ST} = \sqrt{\frac{\text{Total variation within sub-groups}}{\text{(Total sample size – number of subgroups)}}}$$

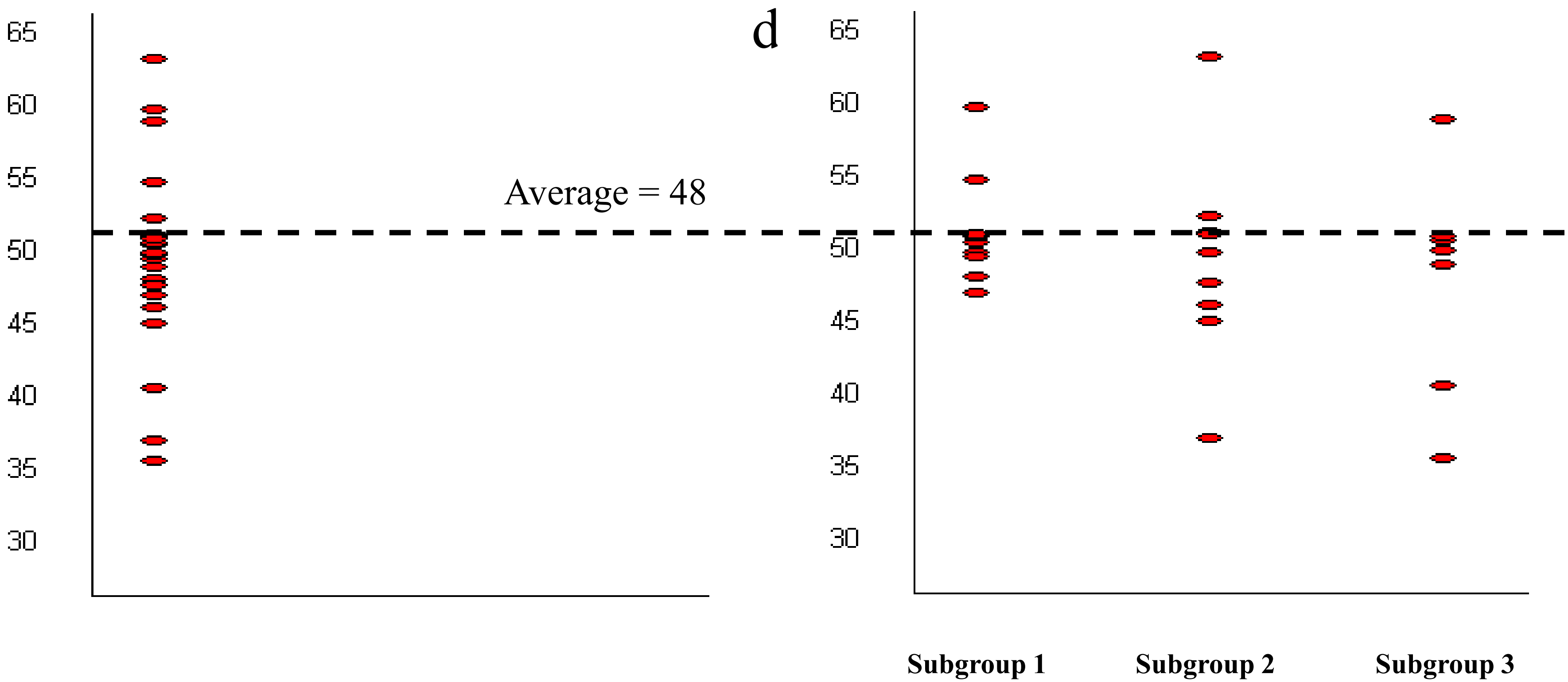
$$S_{ST} = \sqrt{1023.8 / 27} = 6.2$$

$$\text{Sigma long term } S_{LT} = \sqrt{\frac{\text{Overall variation}}{\text{(Total sample size – 1)}}}$$

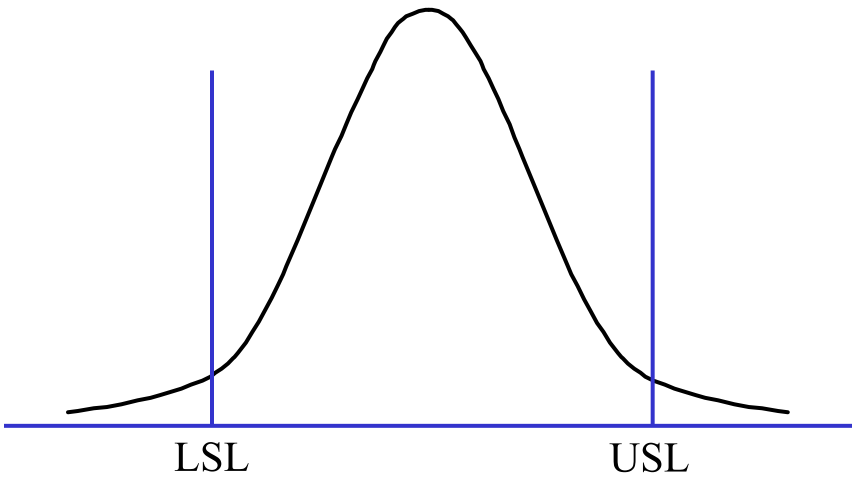
$$S_{LT} = \sqrt{1185.5 / 29} = 6.4$$

Analyzing the Sub-group Data

- Below 2 graphs illustrate the overall variation vis-à-vis sub-group variation



Process Capability (CP)

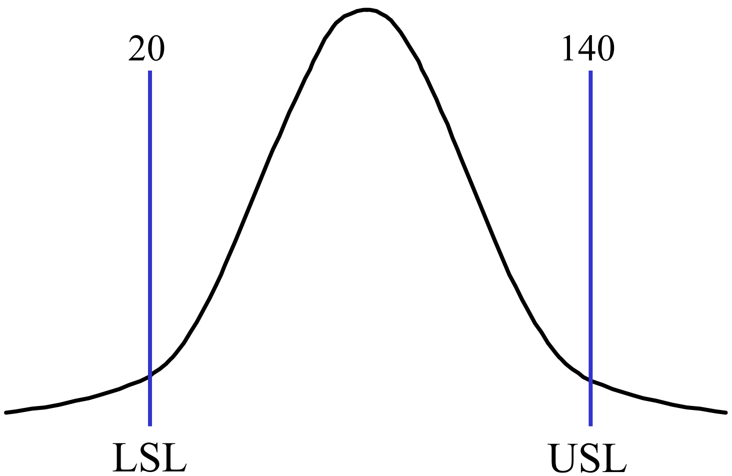


$$\text{Process Capability } C_P = \frac{USL - LSL}{6\, S_{ST}}$$

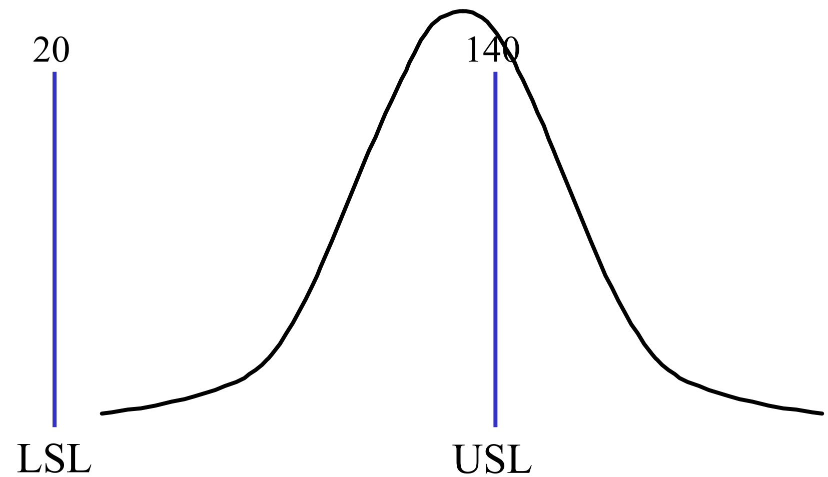
$$Z_{ST} = 3\, C_P$$

- C_P is a measure of short term process capability
- C_P relates the process short term variation with the customer specification limits
- It does not take into account how <u>centered</u> data is
- For a six sigma process, $C_P = 2$ ($Z_{ST} = 3 * 2 = 6$)
- That means this process can fit 12 standard deviations between USL & LSL

Limitations of Process Capability (CP)



$S_{ST} = 10$ | $C_P = 2$ | $Z_{ST} = 6$



$S_{ST} = 10$ | $C_P = 2$ | $Z_{ST} = 6$

- Even though almost 40% of the data is outside specification limits in graph 2, it is still a Six Sigma capable process, however, not performing to its potential
- C_P can not be used for one-sided specifications
- To address these issues, another measure, called C_{PK} is used K stands for Katayori, which means shift of the process and measures the amount of potential capability lost due to poor centering of the process

Capability Index (CPK)

$$C_{PU} = \frac{USL - \bar{Y}}{3\,S_{ST}}$$

$$C_{PL} = \frac{\bar{Y} - LSL}{3\,S_{ST}}$$

$$C_{PK} = \text{Minimum}\,(C_{PU}, C_{PL})$$

$$Z_{ST} = 3\,C_{PK}$$

For one sided specifications

- C_{PK} is a measure of actual short term process performance
- It considers the data centering & forces the mean to be between the specifications
- C_{PK} enables Z_{ST} computation for one sided specifications
- $C_P >= C_{PK}$
- If C_P is >>> C_{PK}, process is capable but not performing up to its potential

Performance Index (PPK)

$$P_{PU} = \frac{USL - \bar{Y}}{3\, S_{LT}}$$

$$P_{PL} = \frac{\bar{Y} - LSL}{3\, S_{LT}}$$

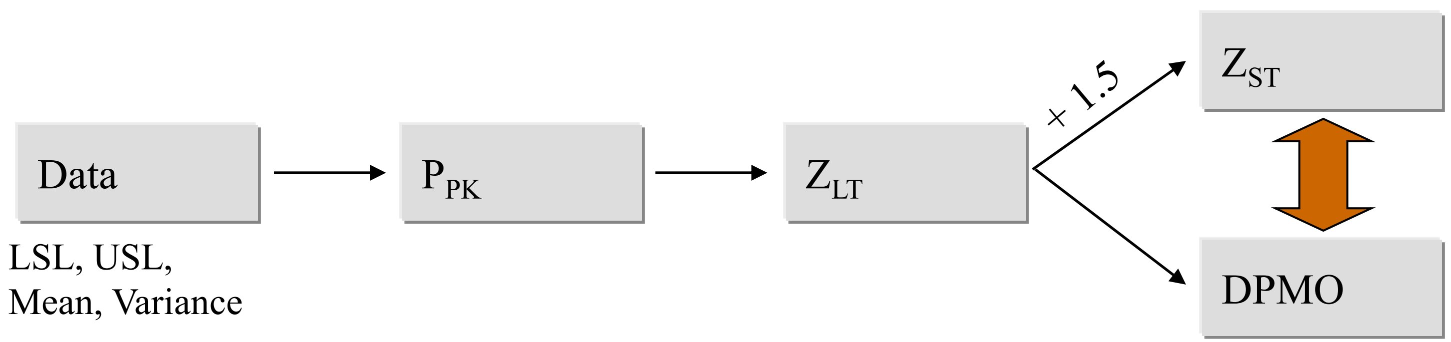
$$P_{PK} = \text{Minimum}\,(P_{PU}, P_{PL})$$

$$Z_{LT} = 3\, P_{PK}$$

- P_{PK} is a measure of actual long term process performance
- It is similar to C_{PK} except that it uses the long term standard deviation
- P_{PK} enables Z_{LT} computation for both one sided & two sided specifications
- Difference between P_{PK} & C_P indicates the shift in the process

Key Concepts

- Capability is an internal measurement of the process behavior
- Performance is an external view of the process behavior
- Processes studied in actual projects may not have a shift of 1.5
- Due to limitations of multiple shift factors & C_P, process sigma multiple calculations for continuous data start from P_{PK}



Visualizing the Continuous Data

Pizza Delivery Time (Minutes)		
Day 1	**Day 2**	**Day 3**
48	50	49
49	48	48
48	36	39
53	50	49
58	50	34
50	62	33
46	45	57
50	47	48
49	51	47
47	44	39

Computing Sigma Multiple for Pizza Delivery

- Assume that the customers expect the pizza delivered latest within 1 hour (USL)

We already know that

Mean = 47.5 $\quad S_{ST} = 6.2 \quad S_{LT} = 6.4$

$$P_{PU} = \frac{USL - \bar{Y}}{3\, S_{LT}} = \frac{60 - 47.5}{3 * 6.4} = 0.65$$

$$P_{PK} = 0.65$$

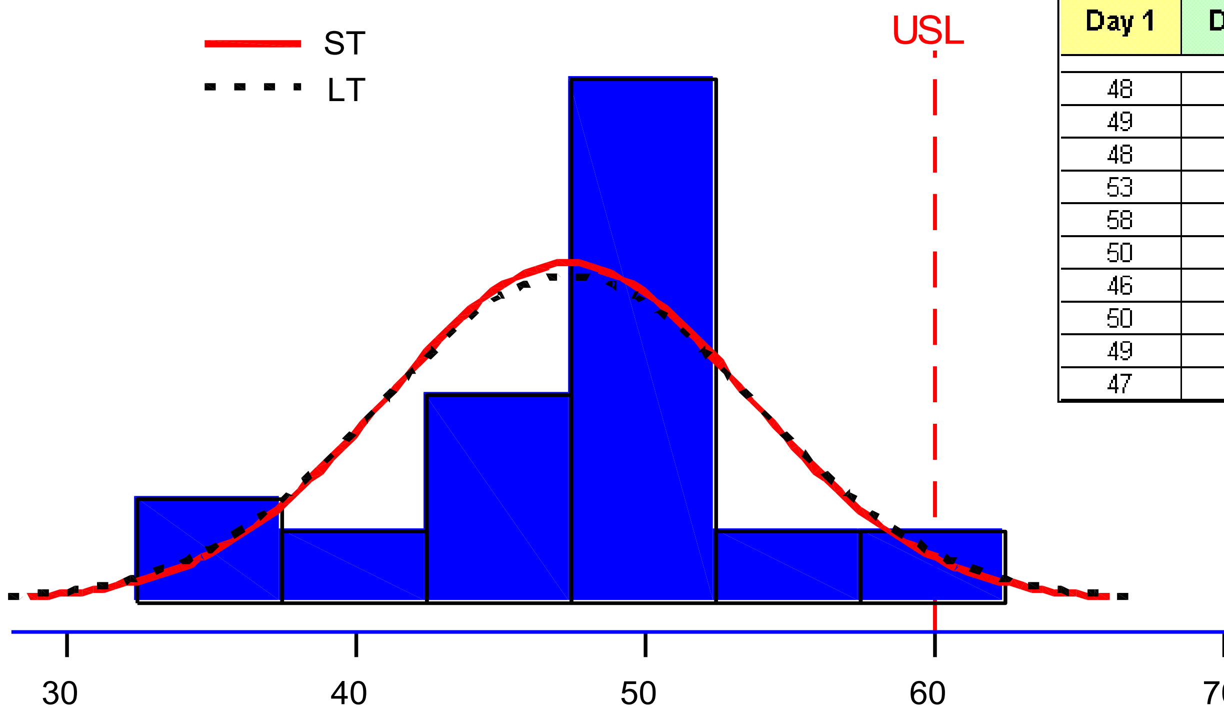
$$Z_{LT} = 3 * 0.65 = 1.95$$

$$DPMO = 25588$$

$$Z_{ST} = 1.95 + 1.5 = 3.45$$

Using Minitab for Continuous Data Z Calculation

Process Capability Analysis for time taken in pizza delivery



Day 1	Day 2	Day 3
48	50	49
49	48	48
48	36	39
53	50	49
58	50	34
50	62	33
46	45	57
50	47	48
49	51	47
47	44	39

Process Data

USL	60.0000
Target	*
LSL	*
Mean	47.4667
Sample N	30
StDev (ST)	6.21507
StDev (LT)	6.44895

Potential (ST) Capability

Cp	*
CPU	0.67
CPL	*
Cpk	0.67
Cpm	*

Overall (LT) Capability

Pp	*
PPU	0.65
PPL	*
Ppk	0.65

Observed Performance

PPM < LSL	*
PPM > USL	33333.33
PPM Total	33333.33

Expected ST Performance

PPM < LSL	*
PPM > USL	21868.43
PPM Total	21868.43

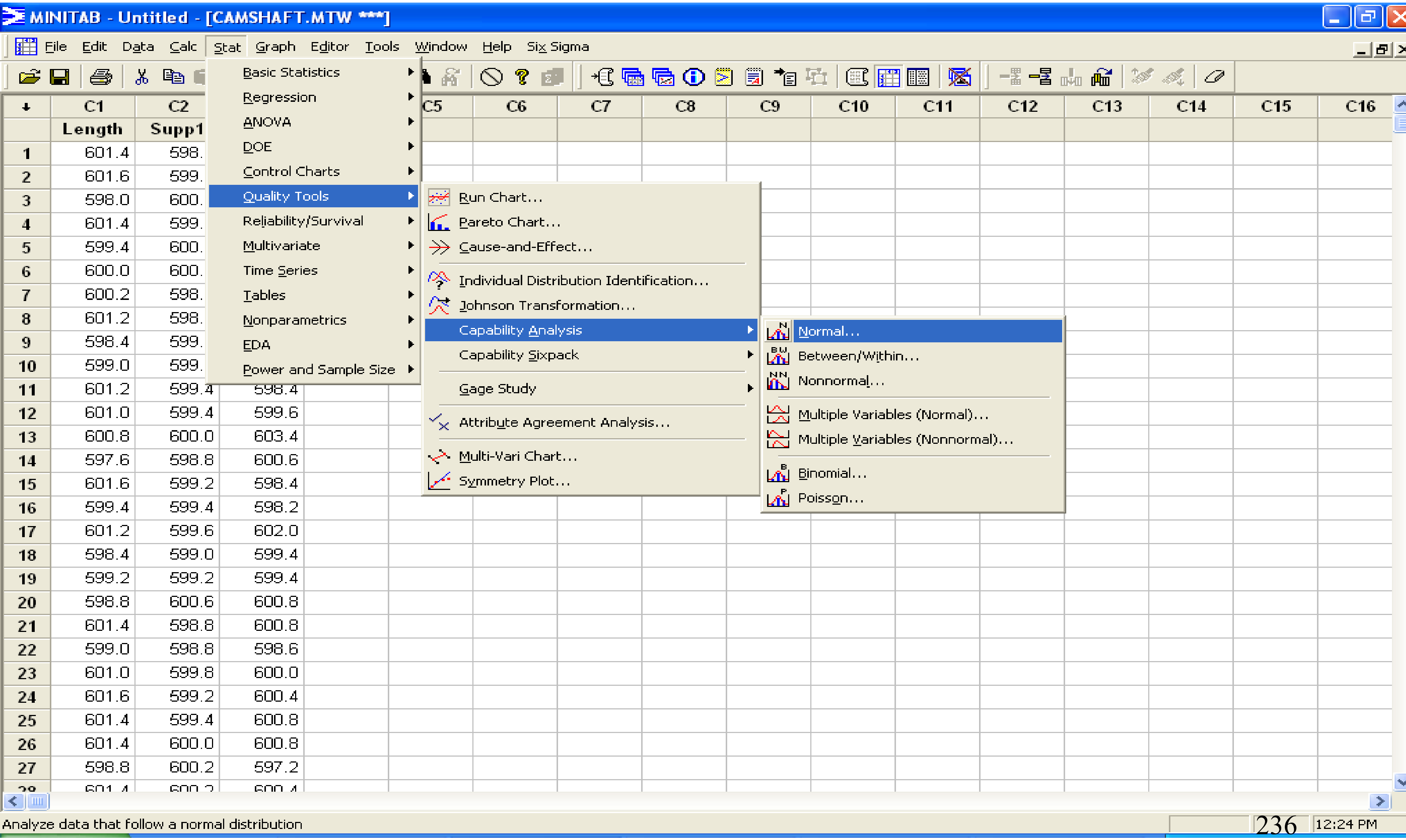
Expected LT Performance

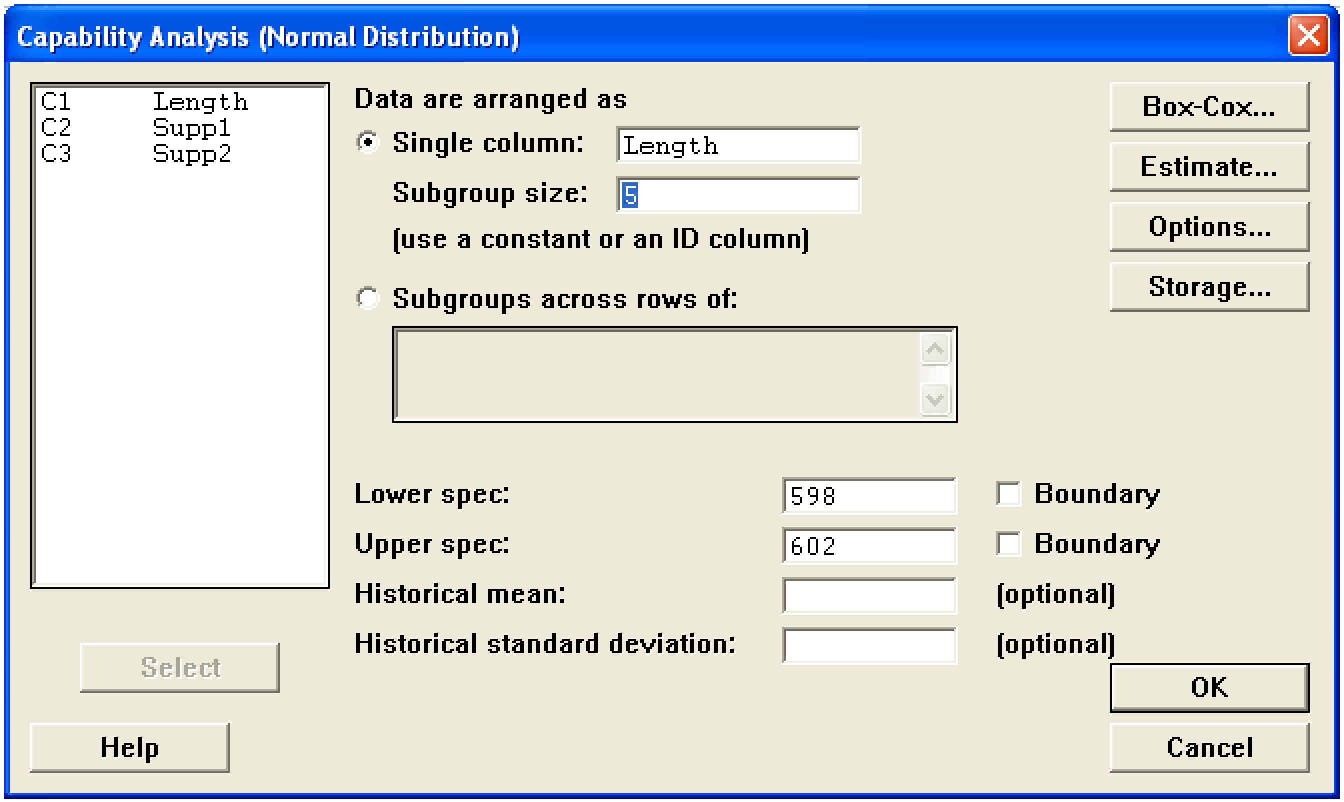
PPM < LSL	*
PPM > USL	25979.72
PPM Total	25979.72

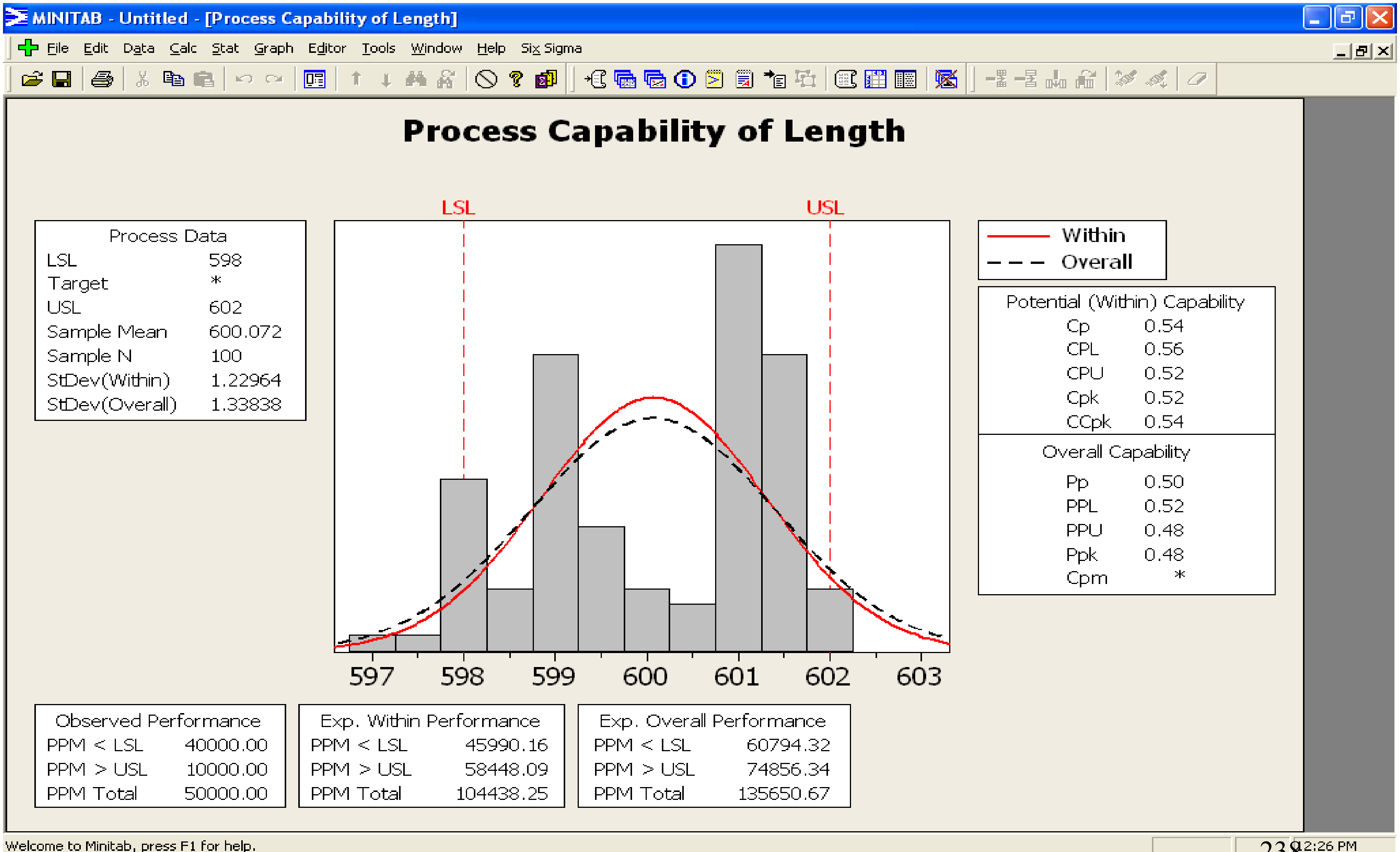
Key Concepts

- There is hardly any shift in the process
- Observed performance indicates the DPMO calculation if the data is treated as discrete (i.e. > 60 & <= 60)
- Expected DPMO values are different from the observed DPMO because expected values are calculated as per the fitted normal probability distribution
- DPMO of the process is 25979, as per the expected long term performance

Process Capability (Minitab)




Capability Analysis (Normal Distribution)
C1 Length
C2 Supp1
C3 Supp2
Data are arranged as
Single column: Length
Subgroup size: 5
(use a constant or an ID column)
Subgroups across rows of:
Lower spec: 598
Upper spec: 602
Historical mean:
Historical standard deviation:
Boundary
Boundary
(optional)
(optional)
Box-Cox...
Estimate...
Options...
Storage...
Select
Help
OK
Cancel


MINITAB - Untitled - [Process Capability of Length]
File Edit Data Calc Stat Graph Editor Tools Window Help Six Sigma
Process Capability of Length
LSL
USL
Process Data
LSL 598
Target *
USL 602
Sample Mean 600.072
Sample N 100
StDev(Within) 1.22964
StDev(Overall) 1.33838
Within
Overall
Potential (Within) Capability
Cp 0.54
CPL 0.56
CPU 0.52
Cpk 0.52
CCpk 0.54
Overall Capability
Pp 0.50
PPL 0.52
PPU 0.48
Ppk 0.48
Cpm *
597 598 599 600 601 602 603
Observed Performance
PPM < LSL 40000.00
PPM > USL 10000.00
PPM Total 50000.00
Exp. Within Performance
PPM < LSL 45990.16
PPM > USL 58448.09
PPM Total 104438.25
Exp. Overall Performance
PPM < LSL 60794.32
PPM > USL 74856.34
PPM Total 135650.67
Welcome to Minitab, press F1 for help.
12:26 PM

Non Normal Data

What to do when the data is Non-Normal

- Transform your data from non-normal to normal.
  - Possibilities:
    - Take the log (any base) of your raw measurements.
    - Raise your individual measurements to a **power**. (Skewed to the right? Try powers less than 1.)
    - Use the **reciprocal** (1/y) of your individual measurements

OR

- **Collect more data (usually >25-30 points for each factor being investigated)**

Caution in Data Transformation!

- When you transform your data, you must also transform your specs.
- You will use the transformed data through out the analysis of your data.
- **Use transformation of data as the last resort after checking all other alternatives such as more data collection, validating data consistency or use of tools that are robust to normality assumption**

Transformation using Box Cox Method

- When continuous data or variable data collected does not show normality, the data can be transformed using equations which will convert the data to normal
- Box Cox is the most commonly used variance stabilizing transformation model
- The method used is first to estimate the appropriate lambda, and then based on the lambda value the mathematical transformations to be carried out
- Data transformation using Box Cox method involves determination of the appropriate λ (lambda) value in the following transformation equation
  - $Y_T = Y^{\lambda}$ when λ is not equal to 0.
  - $Y_T = \text{Log}_e(Y)$, when $\lambda = 0$

    Where Y_T is the transformed data and Y the original data.

Box and Cox Transformation

- For carrying Box Cox Transformation in Minitab follow:
  - **Stat > Control Chart > Box Cox**

- Having done the Box Cox transformation we need to determine the optimal λ value (which is returned by Minitab in the Box Cox plot).

- This optimal value is used as a guide to choose the practical λ value. Thus if $\lambda = -1.034$ is the returned optimal value by Minitab, a practical value would be $\lambda = -1$.

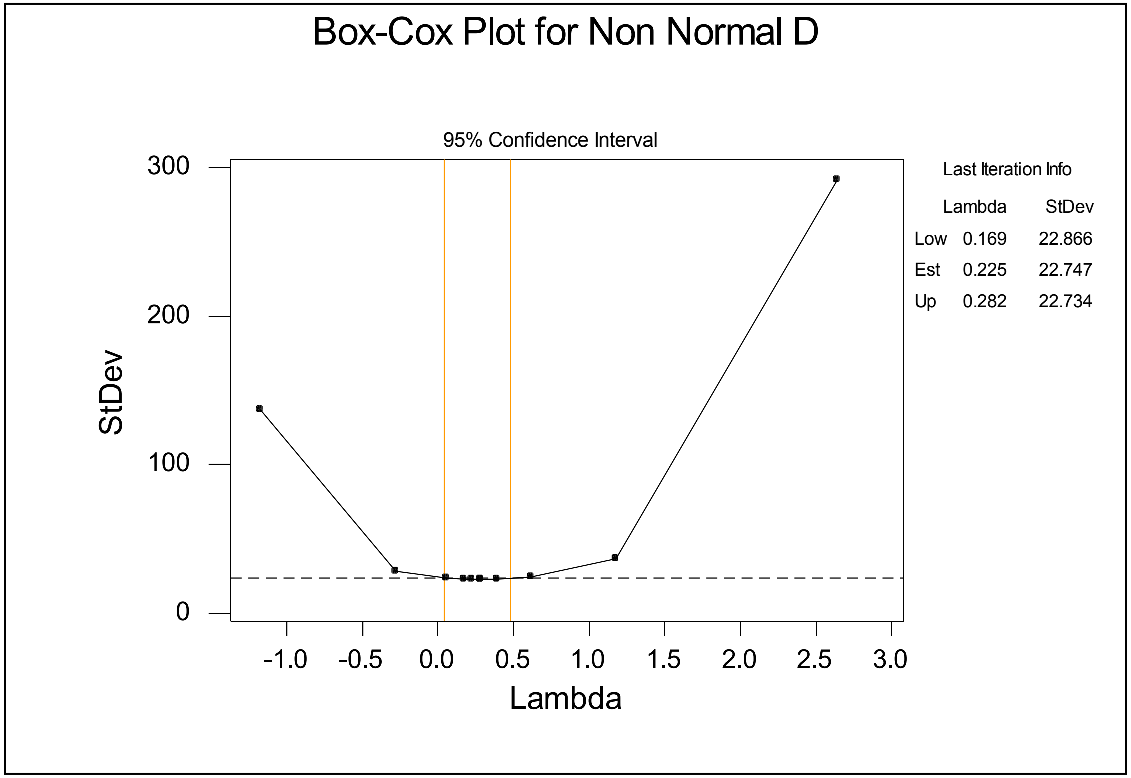
- Thus when
  - $\lambda = 1$, there is no transformation
  - $\lambda = -1$, $Y_T = 1/Y$
  - $\lambda = 0.5$, $Y_T = \text{SQRT}(Y)$

Box and Cox Transformations

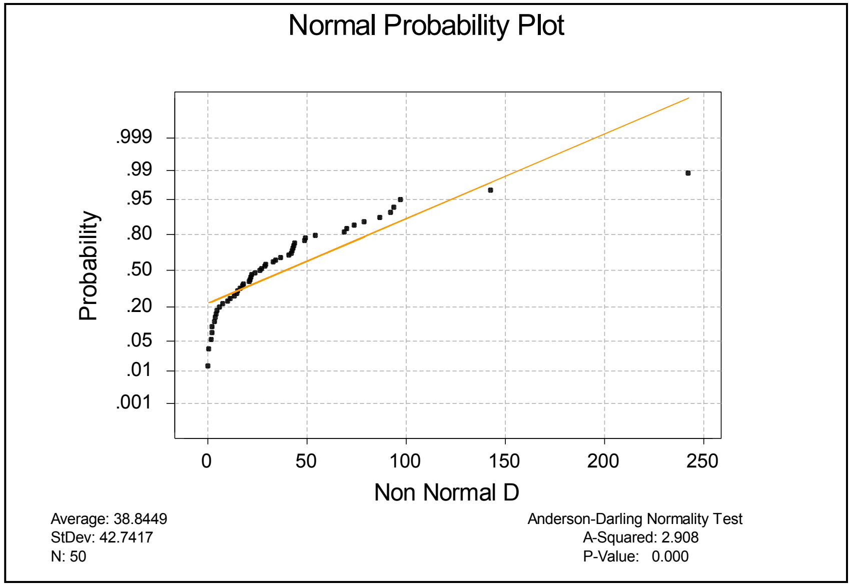
Lambda value	Transformation
2	$Y' = Y^2$
0.5	$Y' = \sqrt{Y}$
1	No transformation
0	$Y' = \ln Y$
-0.5	$Y' = 1/\sqrt{Y}$
-1	$Y' = 1/Y$
-2	$Y' = 1/(Y^2)$

Interpreting Box Cox Plots

- The estimated or optimal λ is 0.225, with the competing λ values on the upper side being 0.282 and on the lower side 0.169.
- The practical value of λ in this case could be $1/4^{th}$ root implying a fourth root transformation
- The red vertical lines represent the 95% confidence interval of the true value of λ .
- Should λ =1 be found within this confidence interval we do not need to transform the data.

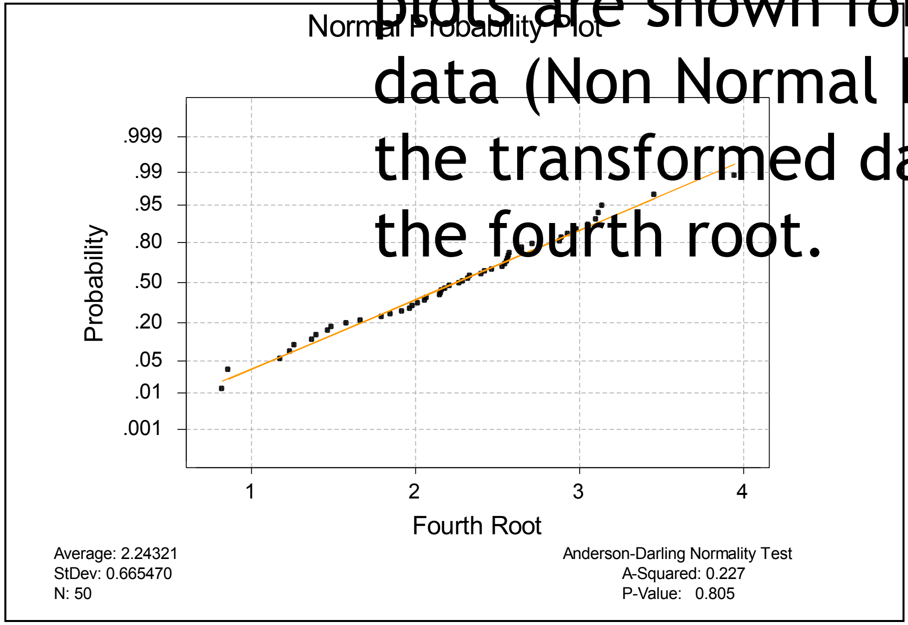


Normality Plots for transformed data

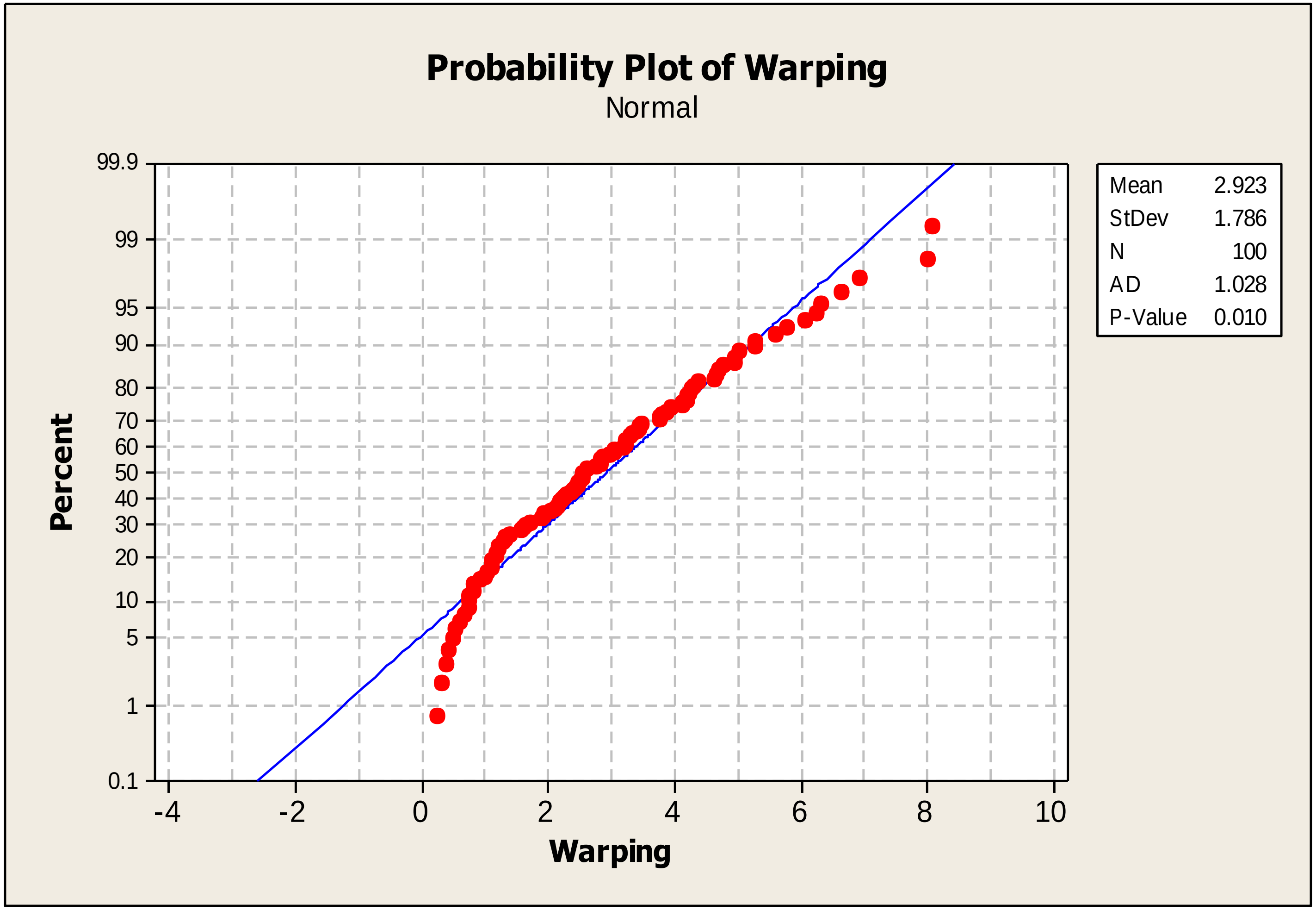


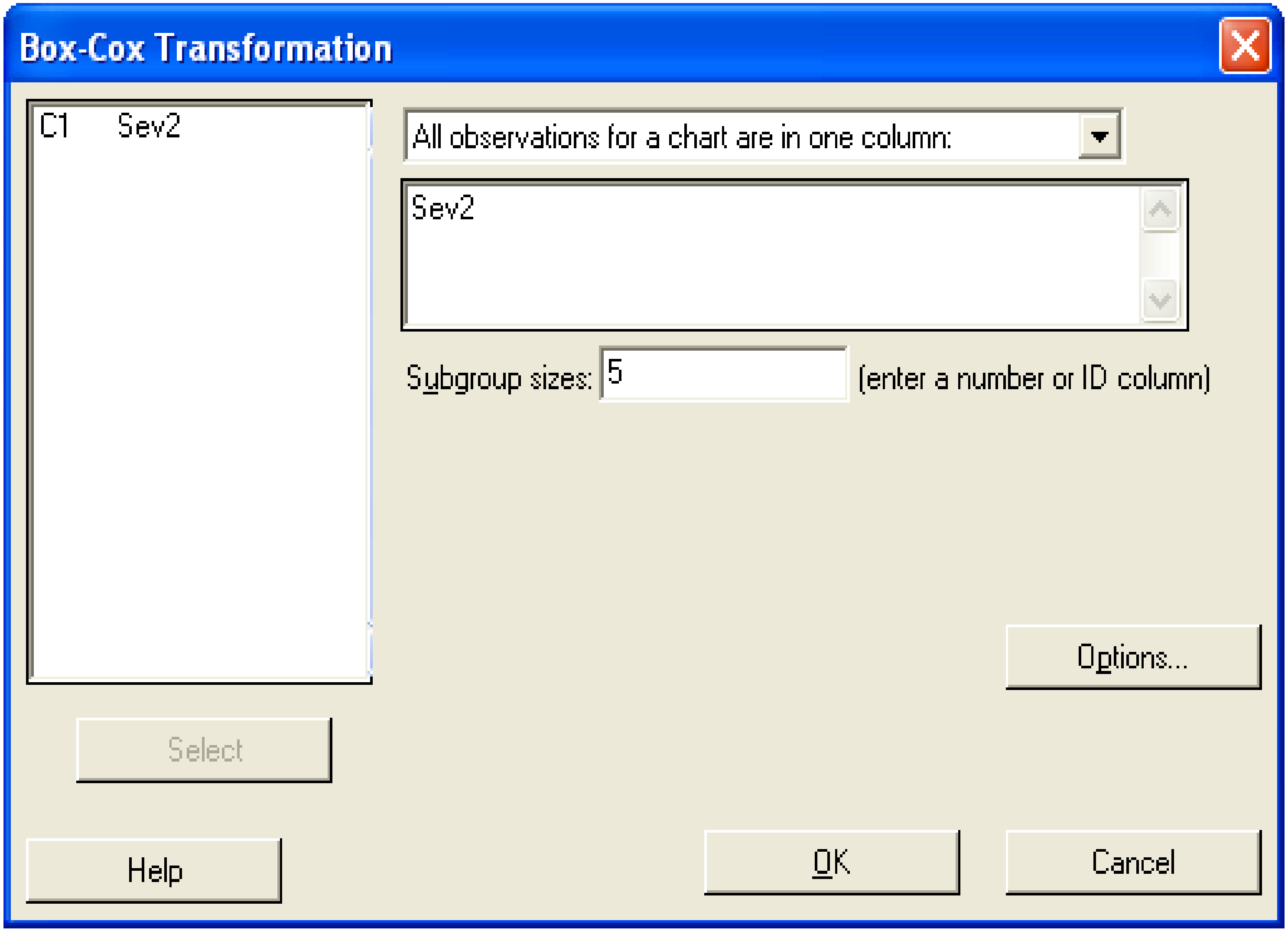
- The practical value of λ in this case could be 1/4th root implying a fourth root transformation

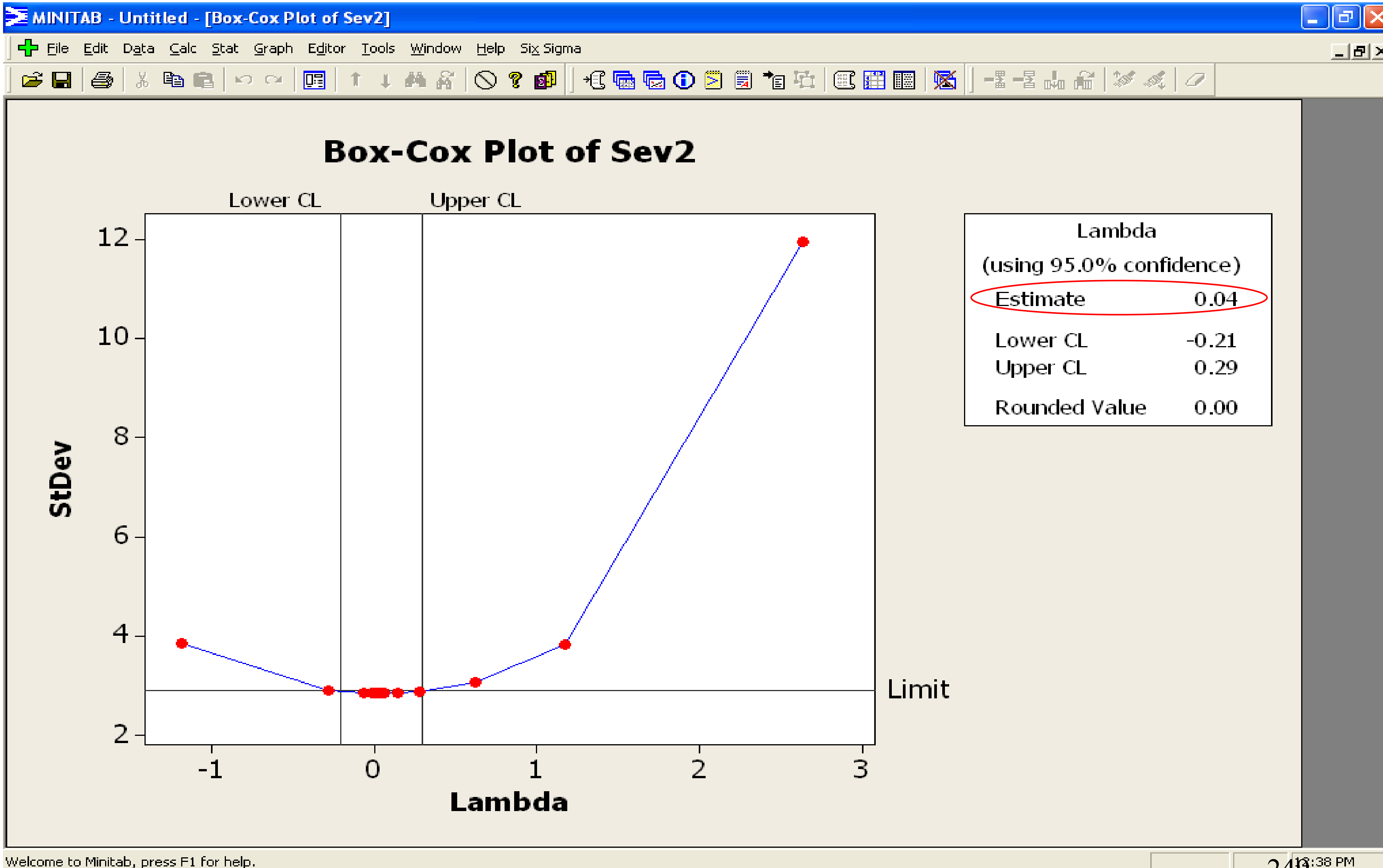
- The adjacent normality plots are shown for the raw data (Non Normal Data) and the transformed data using the fourth root.

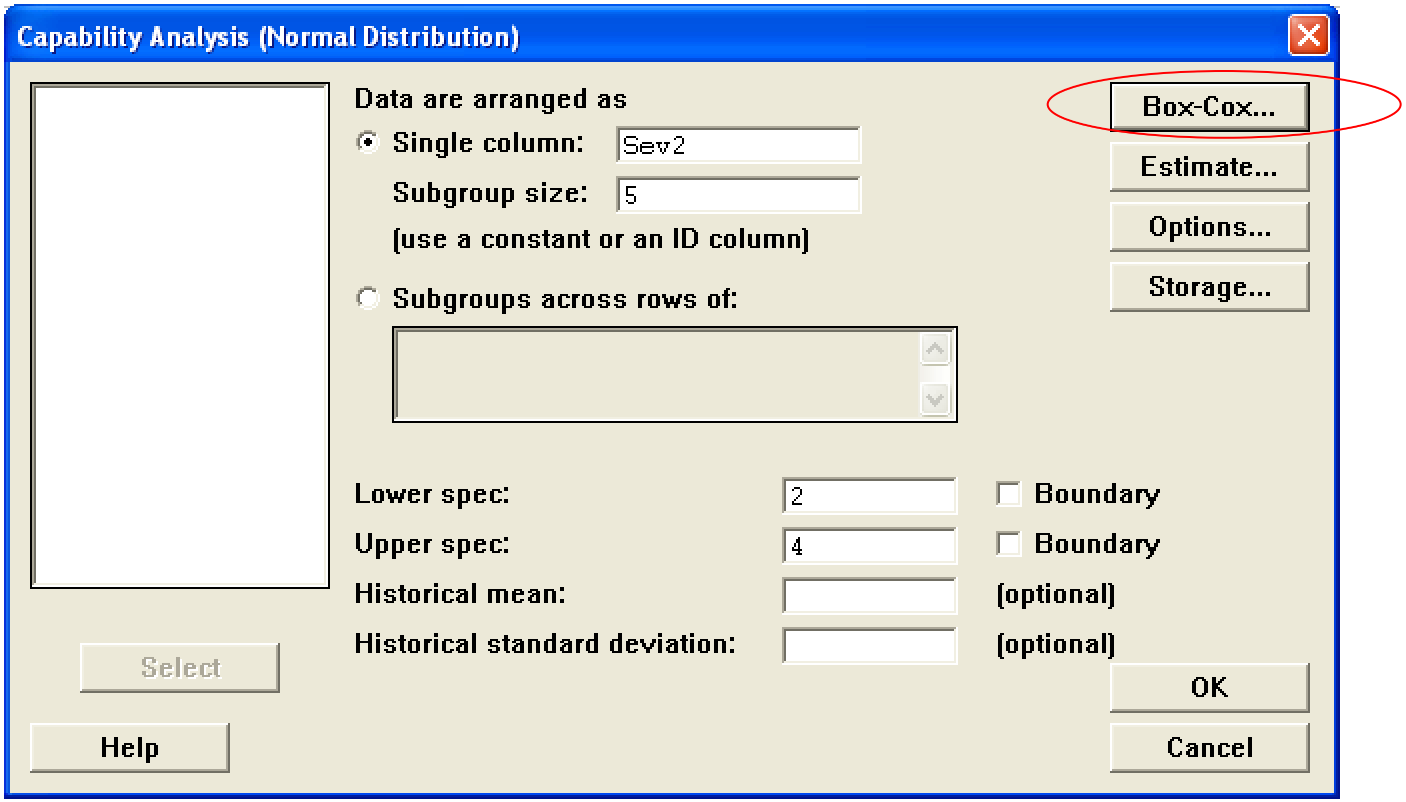


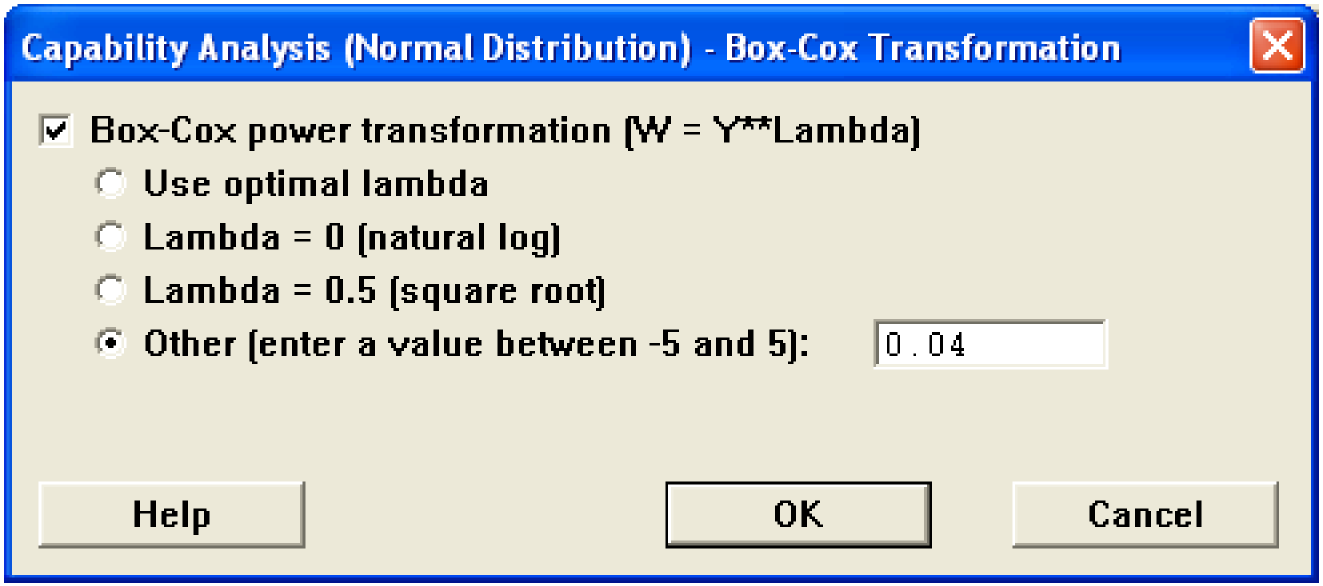
Box-coz Transformation

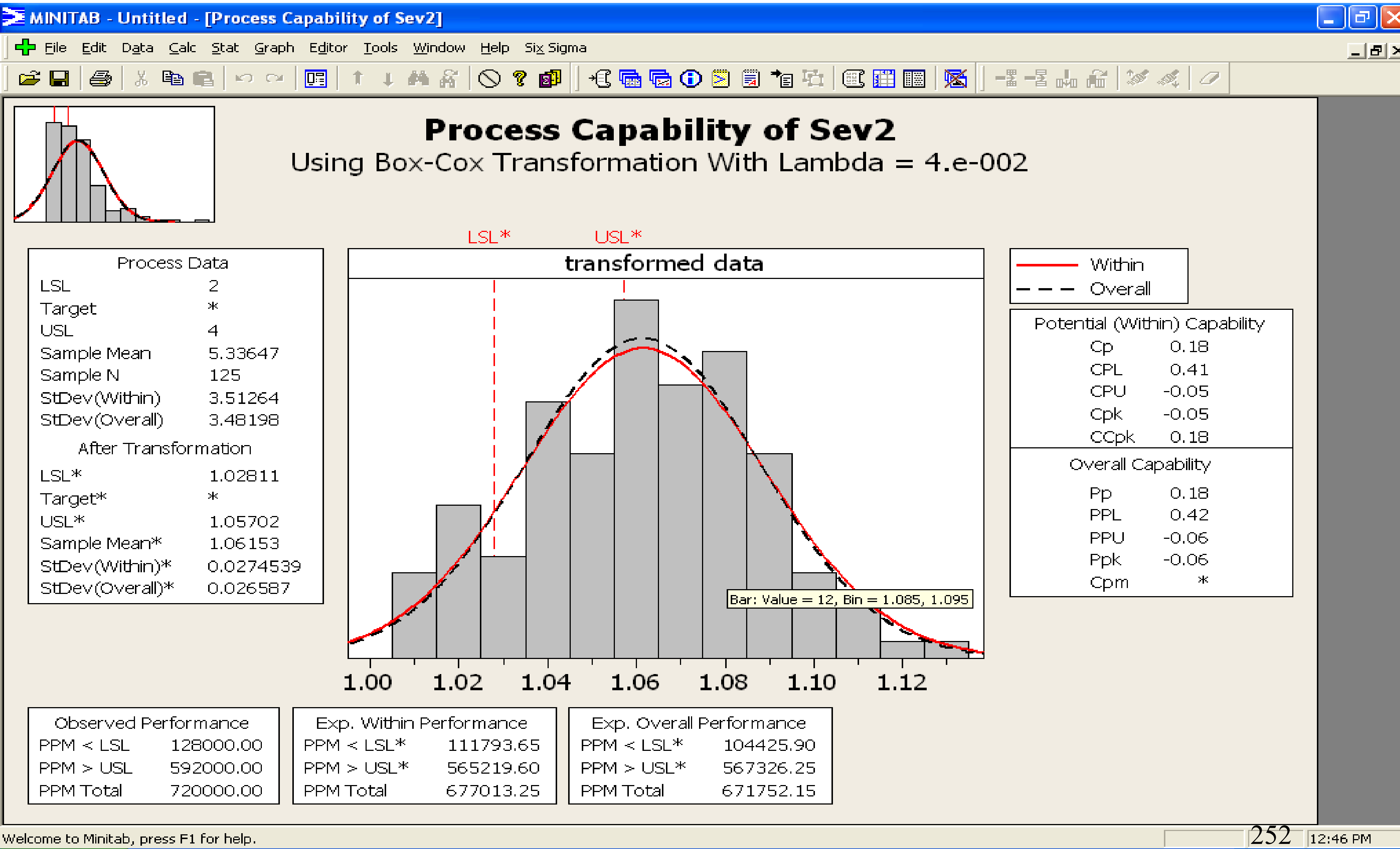



Box-Cox Transformation
C1 Sev2
All observations for a chart are in one column:
Sev2
Subgroup sizes: 5
(enter a number or ID column)
Options...
Select
Help
OK
Cancel


MINITAB - Untitled - [Box-Cox Plot of Sev2]
File Edit Data Calc Stat Graph Editor Tools Window Help Six Sigma
Box-Cox Plot of Sev2
Lower CL
Upper CL
12
10
8
6
4
2
StDev
-1
0
1
2
3
Lambda
Limit
Lambda
(using 95.0% confidence)
Estimate 0.04
Lower CL -0.21
Upper CL 0.29
Rounded Value 0.00
Welcome to Minitab, press F1 for help.
12:38 PM


Capability Analysis (Normal Distribution)
Data are arranged as
Single column:
Sev2
Subgroup size:
5
(use a constant or an ID column)
Subgroups across rows of:
Lower spec:
2
Boundary
Upper spec:
4
Boundary
Historical mean:
(optional)
Historical standard deviation:
(optional)
Select
Help
Box-Cox...
Estimate...
Options...
Storage...
OK
Cancel


Capability Analysis (Normal Distribution) - Box-Cox Transformation
Box-Cox power transformation (W = Y**Lambda)
Use optimal lambda
Lambda = 0 (natural log)
Lambda = 0.5 (square root)
Other (enter a value between -5 and 5):
0.04
Help
OK
Cancel


MINITAB - Untitled - [Process Capability of Sev2]
File Edit Data Calc Stat Graph Editor Tools Window Help Six Sigma
Process Capability of Sev2
Using Box-Cox Transformation With Lambda = 4.e-002
LSL* USL*
transformed data
Process Data
LSL 2
Target *
USL 4
Sample Mean 5.33647
Sample N 125
StDev(Within) 3.51264
StDev(Overall) 3.48198
After Transformation
LSL* 1.02811
Target* *
USL* 1.05702
Sample Mean* 1.06153
StDev(Within)* 0.0274539
StDev(Overall)* 0.026587
Within
Overall
Potential (Within) Capability
Cp 0.18
CPL 0.41
CPU -0.05
Cpk -0.05
CCpk 0.18
Overall Capability
Pp 0.18
PPL 0.42
PPU -0.06
Ppk -0.06
Cpm *
Bar: Value = 12, Bin = 1.085, 1.095
1.00 1.02 1.04 1.06 1.08 1.10 1.12
Observed Performance
PPM < LSL 128000.00
PPM > USL 592000.00
PPM Total 720000.00
Exp. Within Performance
PPM < LSL* 111793.65
PPM > USL* 565219.60
PPM Total 677013.25
Exp. Overall Performance
PPM < LSL* 104425.90
PPM > USL* 567326.25
PPM Total 671752.15
Welcome to Minitab, press F1 for help.
12:46 PM

Process Capability - Non-normal Data

Reasons for Failing a Normality Test

1. A shift occurred in the middle of the data
2. Mixed populations
3. Truncated data
4. Rounding to a small number of values
5. Outliers
6. Too much data
7. The underlying distribution is not normal

Process Capability – Attribute Data

Discrete Probability Distributions

- We have learnt the Normal distribution which is a continuous distribution
- While dealing with discrete data, we must be familiar with discrete distributions
- Two of the useful discrete distributions are
  - Binomial Distribution
  - Poisson Distribution
- Like any probability distribution, these distributions also help in predicting the sample behavior that has been taken from a population

Introduction to Binomial Distribution

- It‛s a probability distribution for <u>discrete data</u>
- Binomial distribution is on <u>*defectives*</u>
- It is named after Swiss mathematician *Jacob Bernoulli*
- It is an application of the population knowledge to predict the sample behavior
- Binomial distribution describes discrete data resulting from a process
  - Tossing of a coin a fixed number of times
  - Success or failure in an interview
- A process is called a Bernoulli processes when
  - Process output has only two possible values (defective / OK, pass / fail, yes / no)
  - Probability of each outcome remains constant over time
  - Outputs are statistically independent

Characteristics of Binomial Distribution

- A Binomial distribution is described by following equation

Probability of exactly r successes out of a sample size of n

$$P(r) = \left(\frac{n!}{r!\,(n-r)!}\right) p^r (1-p)^{n-r}$$

^nC_r

Where p = probability of success

r = number of successes desired

n = sample size

Mean of a Binomial Distribution

$$\mu = n\,p$$

Standard Deviation of a Binomial Distribution

$$\sigma = \sqrt{n\,p\,(1-p)}$$

A! is calculated as follows:

5 ! = 5*4*3*2*1 = 120

4 ! = 4*3*2*1 = 24

Example

- We know that the tossing of a coin has only two outcomes – *head* or *tail*
- Probability of each outcome is 0.5 & it remains fixed over time
- Also, outcomes are statistically independent
- If we want to know what is the probability of getting 5 heads if we toss the coin 8 times, we can use the binomial equation to find that

Here	$p =$	probability of success	$= 0.5$
	$r =$	number of successes desired	$= 5$
	$n =$	sample size	$= 8$

$$P(5) = \frac{8\,!}{5\,!\ (8-5)\,!}\ 0.5^{5}\,(1-0.5)^{8-5} = 21.87\%$$

Introduction to Poisson Distribution

Tool

Poisson Distribution

- It‟s also a probability distribution for <u>discrete data</u>
- Poisson distribution is on <u>*defects*</u>
- It is named after Simeon Denis Poisson
- It is an application of the population knowledge to predict the sample behavior
- Poisson distribution describes discrete data resulting from a process
  - Number of calls received by a call center agent
  - Number of accidents at a signal
- Unlike Binomial distribution that deals with the binary discrete data, a Poisson distribution deals with integers that can take any value

Characteristics of Poisson Distribution

- Let‟s understand the distribution by applying it to number of cars arriving at a particular signal in the rush hour
  - Mean number of cars that arrive at the signal in the rush hour can be known from past data
  - If we divide the rush hour into small intervals of one second each, we can state the following:
    - Probability of exactly one car arriving a the signal in every one second interval is very small & is constant for every one second interval
    - Probability that 2 or more cars will arrive within a second interval can be approximated to zero
    - It does not matter where that one second interval appears in the rush hour
    - Number of cars arriving in one particular second interval is independent of number of cars in another second interval
    - These statements are true for any process that follows Poisson‟s distribution

Characteristics of Poisson Distribution

- A Poisson distribution is described by following equation

Probability of exactly x occurrences in a Poisson distribution $\quad P(x) = \dfrac{\lambda^{x} \; e^{-\lambda}}{x\,!}$

Where	λ (*lambda*)	=	mean number of occurrences during interval
	x	=	number of occurrences desired
	e	=	base of the natural logarithm (equals 2.71828)

Mean of a Poisson Distribution $\quad \mu = \lambda$

Standard Deviation of a Poisson Distribution $\quad \sigma = \lambda$

Example

- Suppose we want to investigate the efficiency of safety measures taken at a dangerous signal. Past records show that mean number of accidents every week is five at this signal. If the number of accidents follow a Poisson distribution than we can calculate the probability of any number of accidents happening in a week.

Given $\lambda =$ 5 per week

Now probability of no accidents per week

$$P(0) = \frac{5^{0} \quad e^{-5}}{0\,!} = 0.006$$

Probability of exactly one accident per week

$$P(1) = \frac{5^{1} \quad e^{-5}}{1\,!} = 0.03$$

Probability of more than two accidents per week =

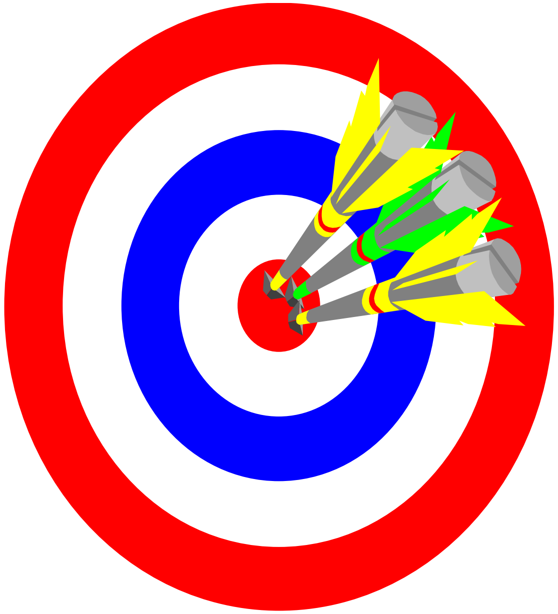
$$= 1 - [\, P(0) + P(1) + P(2) \,]$$

$$1 - [\, 0.006 + 0.03 + 0.08 \,] = 0.884$$

Target – 3.4 dpm

3.4 defects per million

(99.9997% Good Quality)



Cpk / DPM Conversion Table

Cpk	Stable Process - Resultant DPM			
Value	Cp = 2	Cp = 1.5	Cp = 1.33	Cp = 1
0.33	158655	158655	158655	158655
0.5	66807	66807	66807	66810
0.67	22750	22750	22750	22782
0.83	6210	6210	6210	6433
1	1350	1350	1350	2700
1.17	233	233	236	
1.33	33	33	63	
1.5	3.4	7		

- We need a minimum C_{pk} value of 1.5 to achieve 3.4 DPM when we have a stable process
- We can test for stability and calculate C_{pk} for variable data using the Capability Study

PPM / SIGMA / Cpk Conversion Table

RECALL: PPM may or may not = DPMO. Only if each part has one defect type will they be the same value. If one PART has >1 defect opportunity then these values can be drastically different.

*Converting to Cpk from a sigma level is an estimation since Cpk uses the USL or LSL, whichever is closest to the process mean. The opposite side that is not accounted for my have a tail that is unaccounted for.

SIGMA LIMITS (long-term)	% POPULATION WITHIN LIMITS	PPM DEFECTIVE OUTSIDE LIMITS	Cpk*
+/- .6745 Sigma	50.00%	500,000	
+/- 1.00 Sigma	**68.27%**	**317,300**	**0.33**
+/- 2.00 Sigma	**95.45%**	**45,500**	**0.67**
+/- 2.36 Sigma	98.00%	20,000	0.79
+/- 3.00 Sigma	**99.73%**	**2,700**	**1.00**
+/- 3.12 Sigma	99.82%	1,800	1.04
+/- 3.19 Sigma	99.86%	1,400	1.06
+/- 3.23 Sigma	99.88%	1,200	1.08
+/- 3.29 Sigma	99.90%	1,000	1.10
+/- 3.35 Sigma	99.92%	800	1.12
+/- 3.54 Sigma	99.96%	400	1.18
+/- 3.71 Sigma	99.98%	200	1.24
+/- 3.89 Sigma	99.99%	100	1.30
+/- 4.00 Sigma	**99.9937%**	**63**	**1.33**
+/- 4.26 Sigma	99.9980%	20	1.42
+/- 4.42 Sigma	99.9990%	10	1.47
+/- 4.50 Sigma	**99.99966%**	**3.4**	**1.50**
+/- 4.75 Sigma	99.9998%	2	1.58
+/- 4.89 Sigma	99.9999%	1	1.63
+/- 5.00 Sigma	**99.99994%**	**0.6**	**1.67**
+/- 5.20 Sigma	99.99998%	0.2	1.73
+/- 5.32 Sigma	99.99999%	0.1	1.77
+/- 5.61 Sigma	99.999998%	0.02	1.87
+/- 5.73 Sigma	99.999999%	0.01	1.91
+/- 6.00 Sigma	**99.9999998%**	**0.002**	**2.00**

Capability Study – Binomial Data

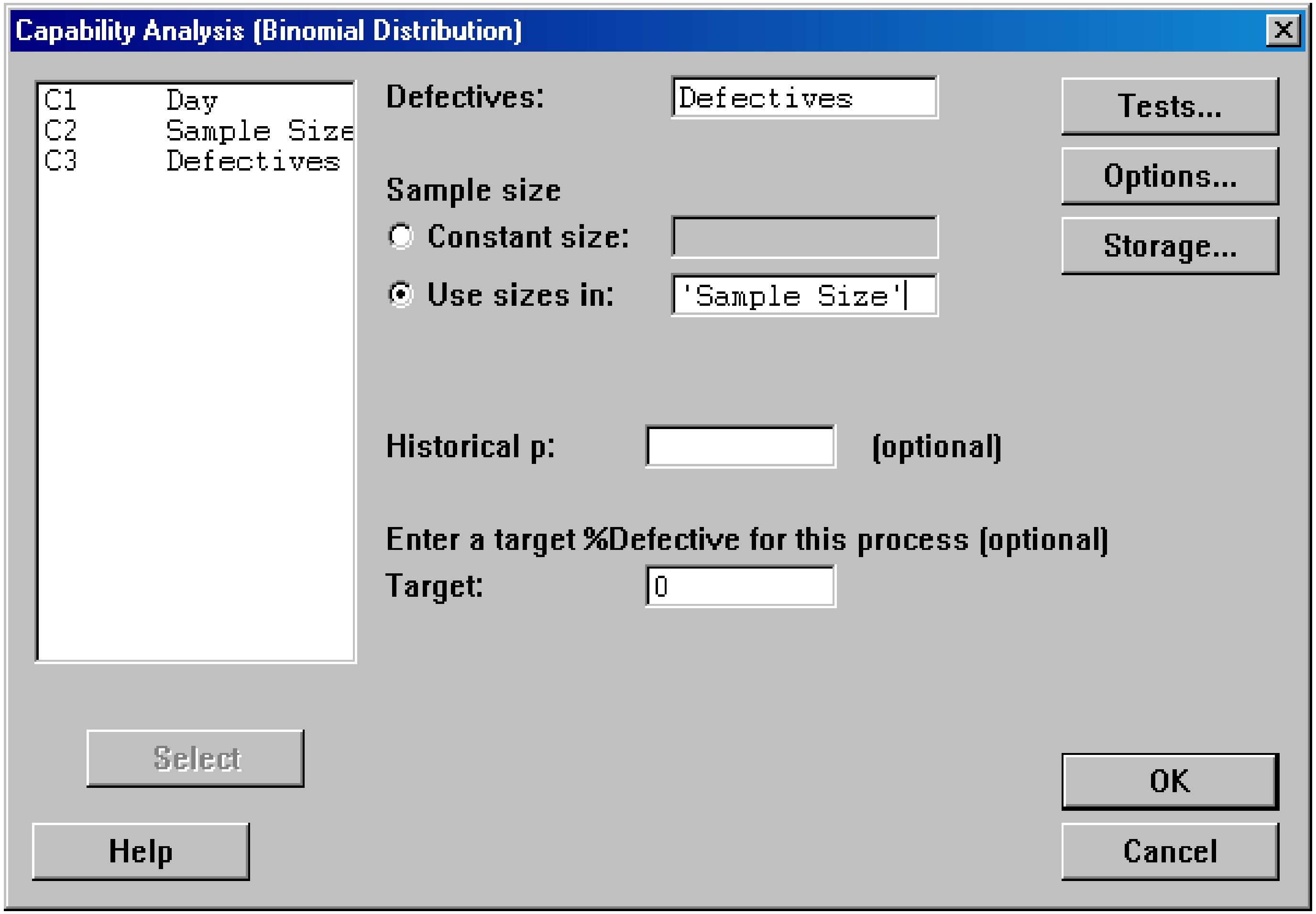
- Over 10 working days a random sample of orders were checked for accuracy
- A pass / fail criteria was used for assessment

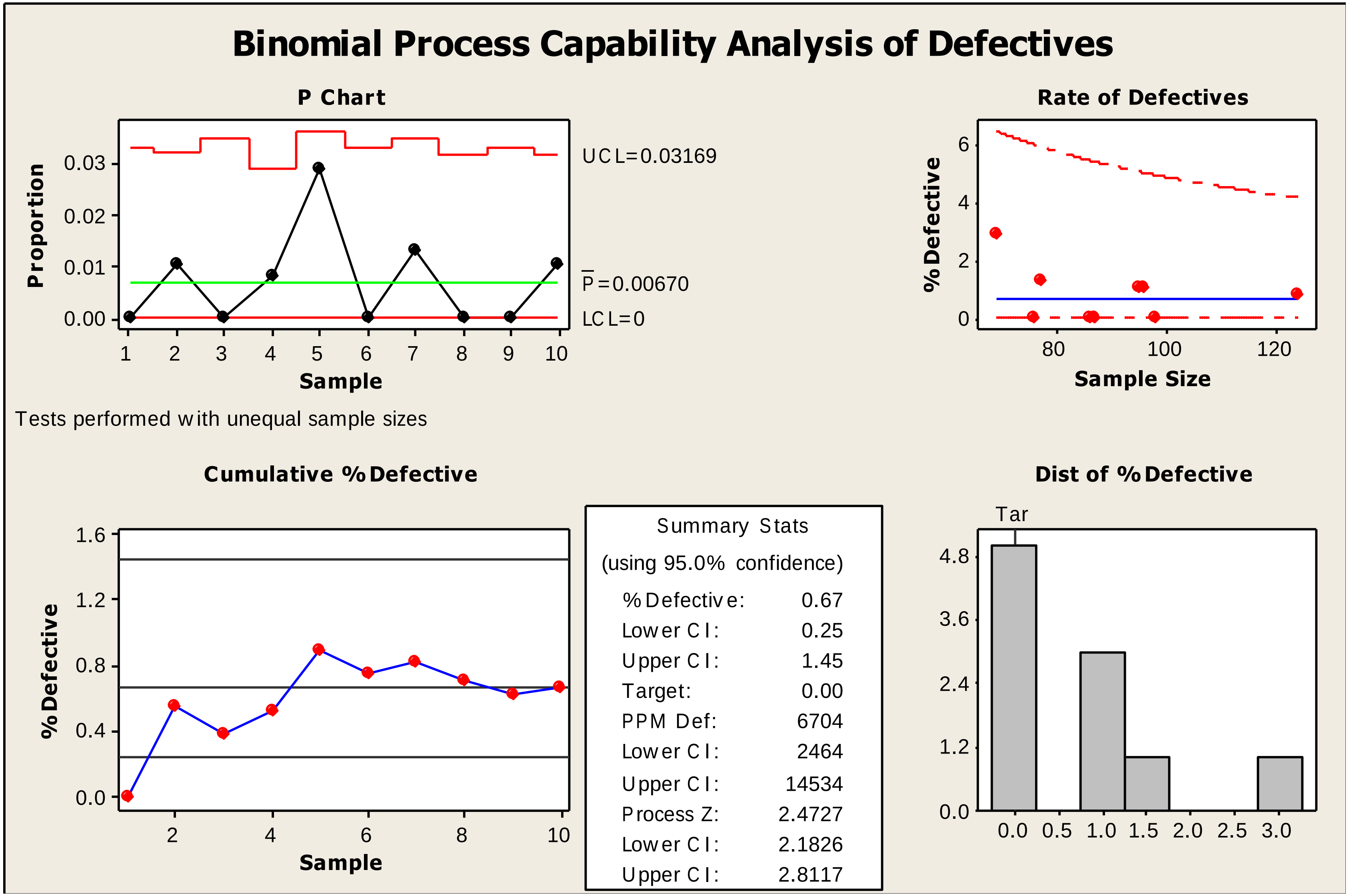
Order Accuracy Data

Day	Sample Size	Defectives
1	87	0
2	95	1
3	76	0
4	124	1
5	69	2
6	86	0
7	77	1
8	98	0
9	87	0
10	96	1

Minitab – Binomial Capability

Open Worksheet: "TSS Binomial Capability"
Select: Stat> Quality Tools>Capability Analysis>Binomial




Binomial Process Capability Analysis of Defectives
P Chart
Proportion
0.03
0.02
0.01
0.00
UCL=0.03169
P̄=0.00670
LCL=0
1 2 3 4 5 6 7 8 9 10
Sample
Tests performed with unequal sample sizes
Rate of Defectives
% Defective
6
4
2
0
80 100 120
Sample Size
Cumulative % Defective
% Defective
1.6
1.2
0.8
0.4
0.0
2 4 6 8 10
Sample
Summary Stats
(using 95.0% confidence)
% Defective: 0.67
Lower CI: 0.25
Upper CI: 1.45
Target: 0.00
PPM Def: 6704
Lower CI: 2464
Upper CI: 14534
Process Z: 2.4727
Lower CI: 2.1826
Upper CI: 2.8117
Dist of % Defective
Tar
4.8
3.6
2.4
1.2
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0

Summary Statistics

Summary Stats

(using 95.0% confidence)

%Defective:	0.67
Lower CI:	0.25
Upper CI:	1.45
Target:	0.00
PPM Def:	6704
Lower CI:	2464
Upper CI:	14534
Process Z:	2.4727
Lower CI:	2.1826
Upper CI:	2.8117

This gives the actual PPM Defective (DPM) = 6704

This value can be converted to an approximate C_{pk} Value using the C_{pk}/DPM conversion table

A 95% confidence interval is returned for DPM

(2464 to 14534)

The confidence interval assumes the process is stable

Capability Study – Poisson Data

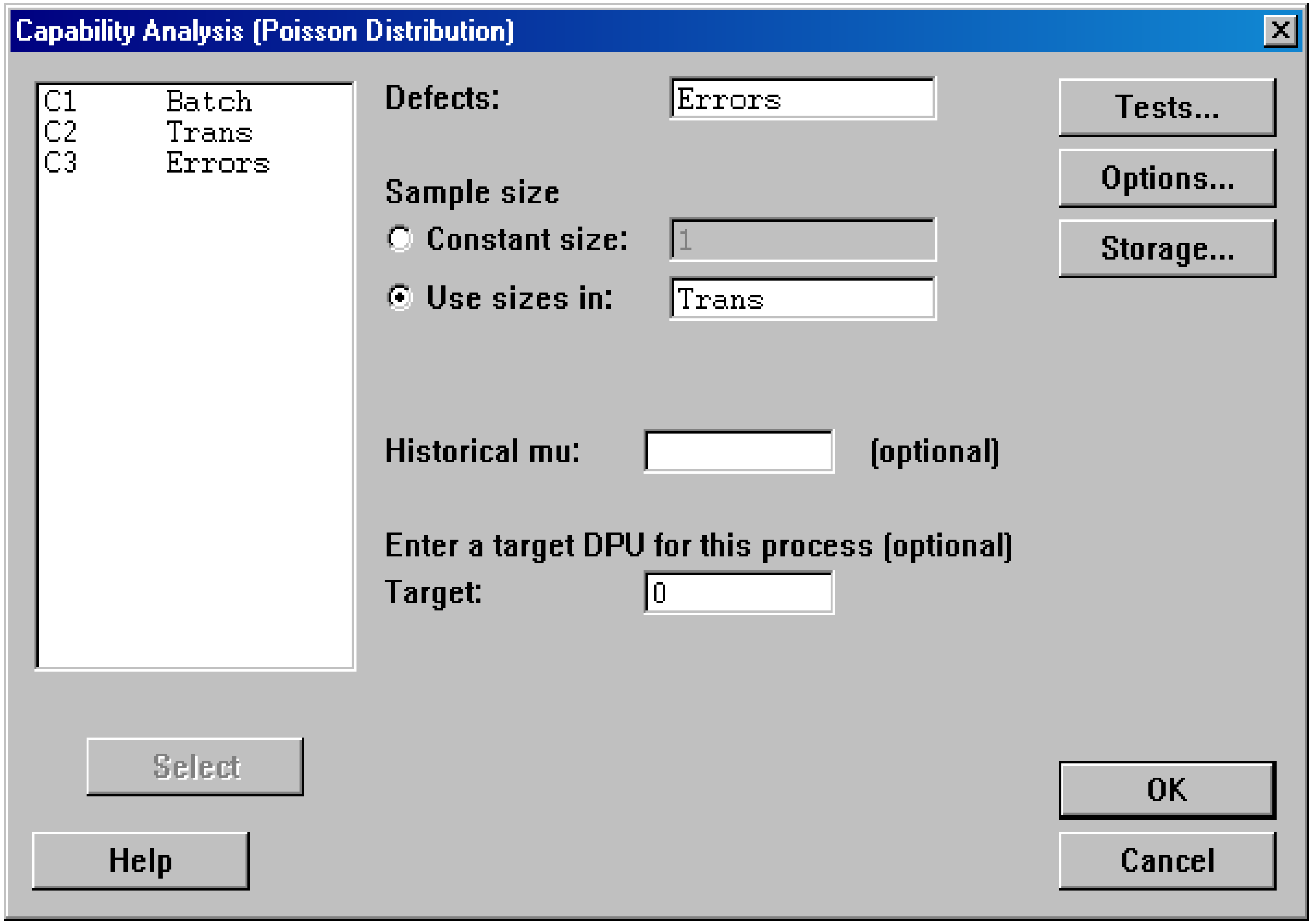
- The data on the next page was collected from 20 consecutive working days
- The data refers to the number of errors found in daily transactions

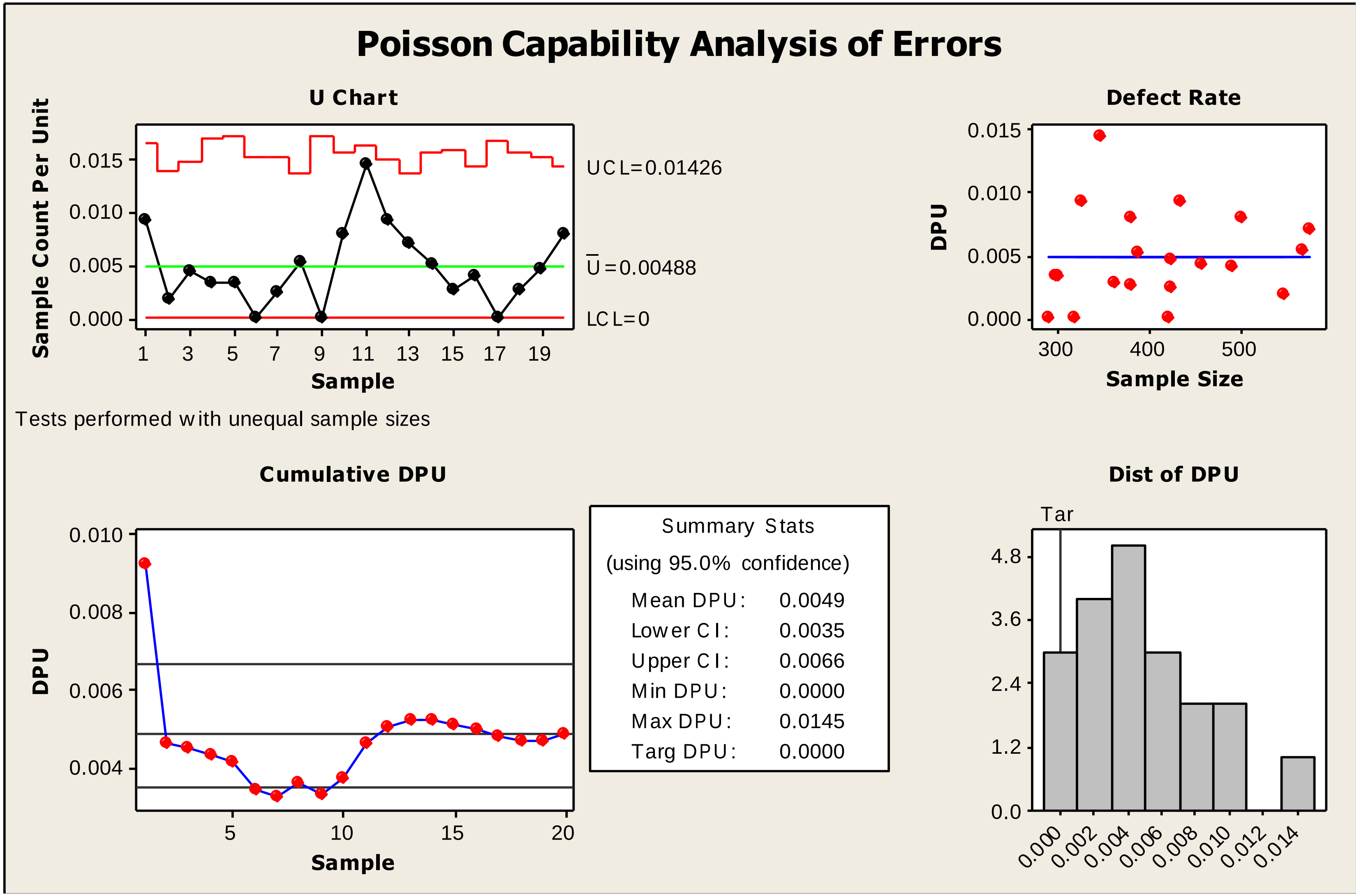
Transactional Errors Data

Day	Trans	Errors	Day	Trans	Errors
1	326	3	11	345	5
2	543	1	12	432	4
3	456	2	13	573	4
4	301	1	14	387	2
5	297	1	15	361	1
6	420	0	16	489	2
7	421	1	17	317	0
8	564	3	18	379	1
9	289	0	19	423	2
10	378	3	20	499	4

Minitab – Poisson Capability

Open Worksheet: "TSS Poisson Capability"
Select: Stat> Quality Tools>Capability Analysis>Poisson




Poisson Capability Analysis of Errors
U Chart
Sample Count Per Unit
0.015
0.010
0.005
0.000
1 3 5 7 9 11 13 15 17 19
Sample
UCL=0.01426
$\bar{U}$=0.00488
LCL=0
Tests performed with unequal sample sizes
Defect Rate
DPU
0.015
0.010
0.005
0.000
300 400 500
Sample Size
Cumulative DPU
DPU
0.010
0.008
0.006
0.004
5 10 15 20
Sample
Summary Stats
(using 95.0% confidence)
Mean DPU: 0.0049
Lower CI: 0.0035
Upper CI: 0.0066
Min DPU: 0.0000
Max DPU: 0.0145
Targ DPU: 0.0000
Dist of DPU
Tar
4.8
3.6
2.4
1.2
0.0
0.000 0.002 0.004 0.006 0.008 0.010 0.012 0.014

Summary Statistics

Summary Stats

(using 95.0% confidence)

Mean DPU:	0.0049
Lower CI:	0.0035
Upper CI:	0.0066
Min DPU:	0.0000
Max DPU:	0.0145
Targ DPU:	0.0000

Yield = $e^{-DPU} = e^{-0.00488} = 0.995131$

This is equivalent to a DPM of 4869

Our DPM of 4869 can be converted to an approximate C_{pk} Value using the C_{pk}/DPM conversion table

A 95% confidence interval is returned for DPU

(0.0035 to 0.0066)

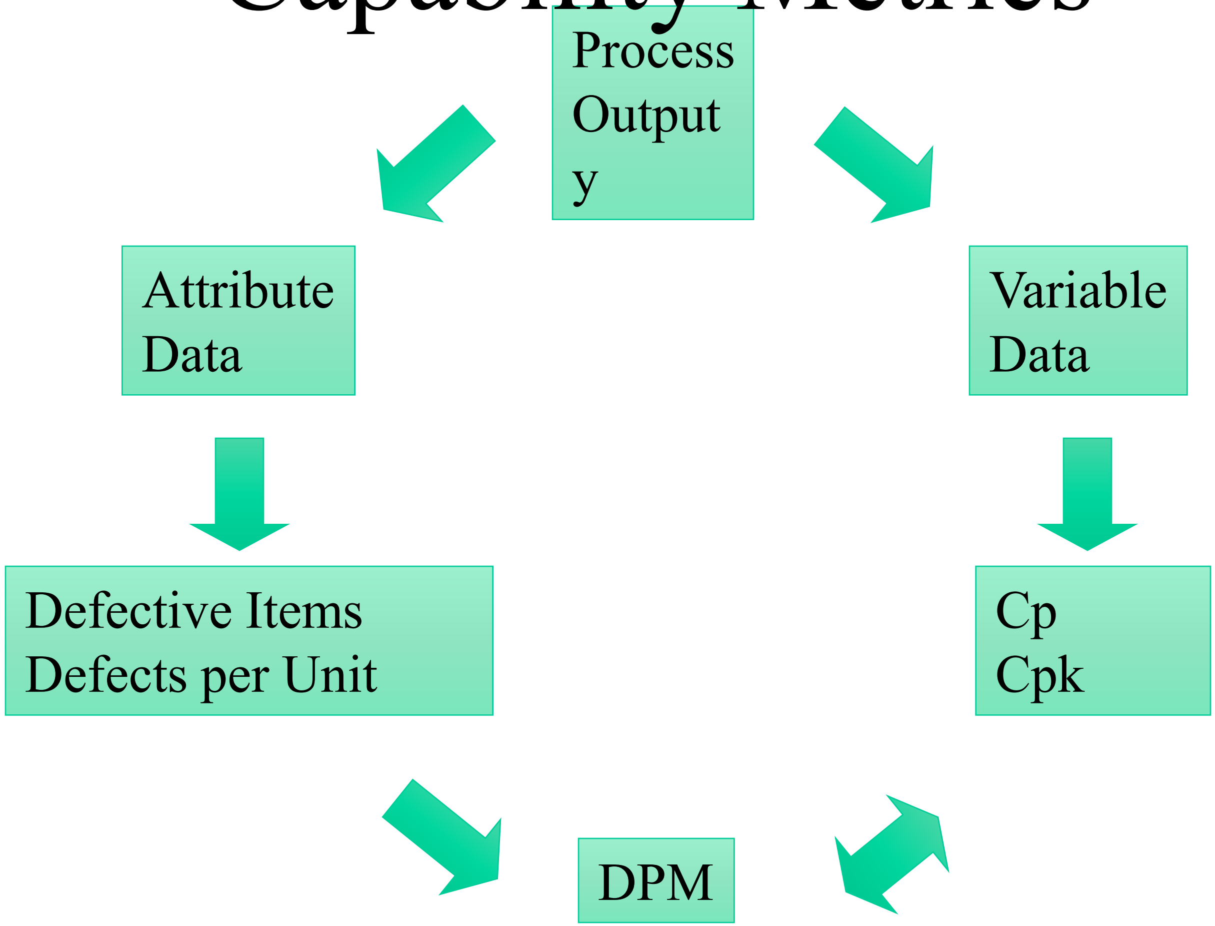
The confidence interval assumes the process is stable

Process Capability – Summary

Variable v Attribute Data

- Variable Data allows us to calculate capability indices (Cp, Cpk) directly
- Achieving a stable process with a Cpk value of 1.5 or more at the end of our project means that we have achieved 6 Sigma
- Achieving a Cpk value of 1.5 for a variable measure (y) would mean that we would have 3.4 DPM or less
- The Six Sigma target for each attribute measure is the same – 3.4 DPM or less

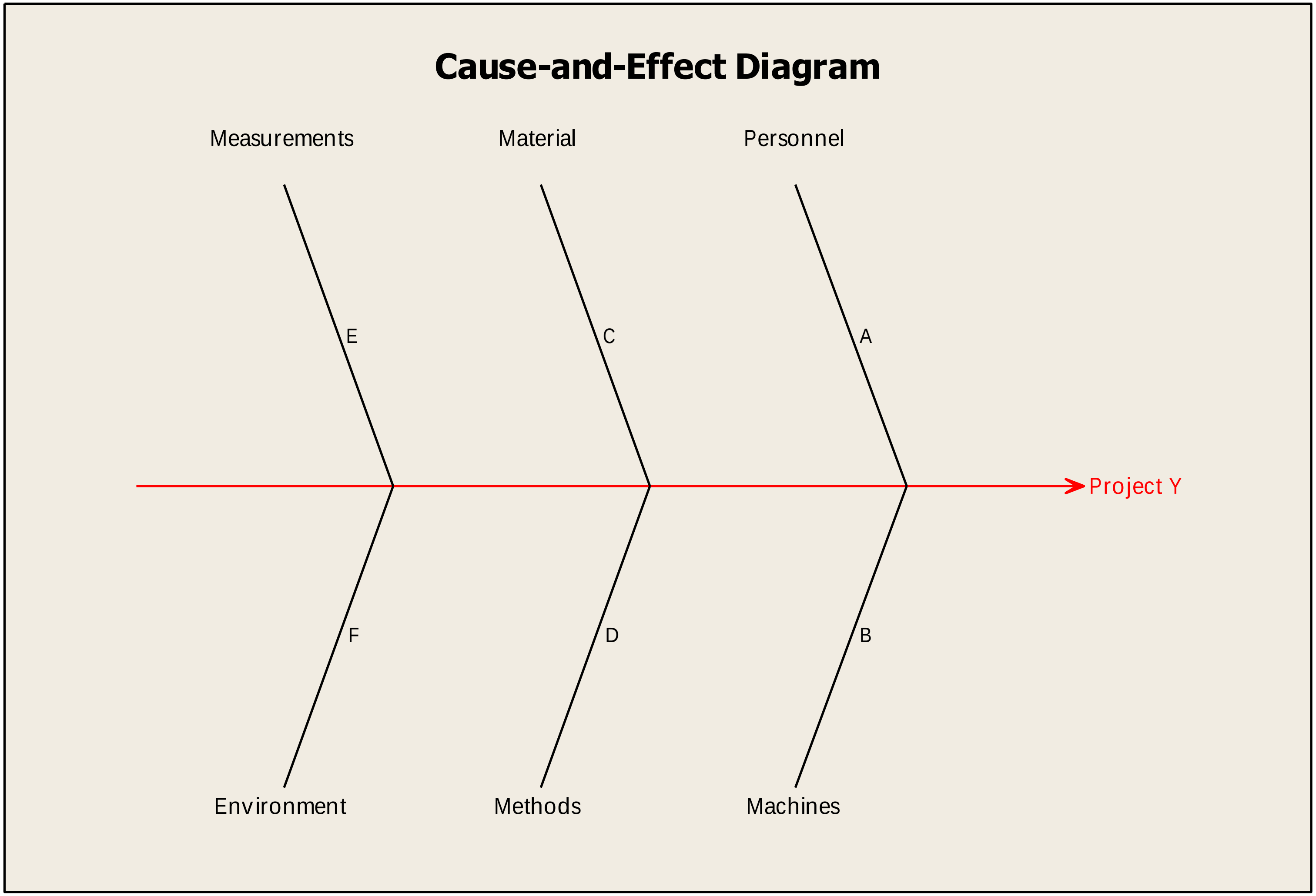
Capability Metrics



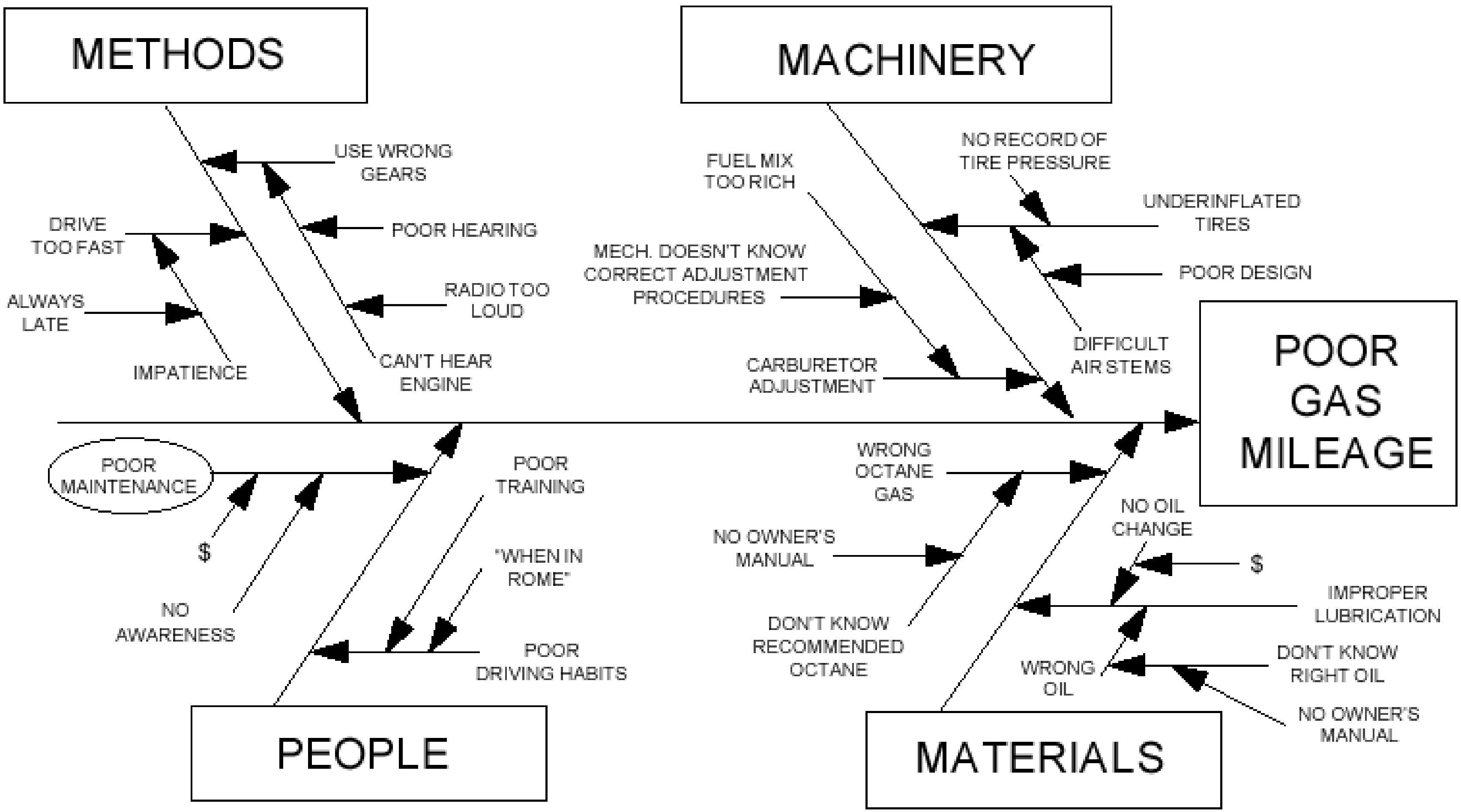
Cause and Effect Analysis (Ishikawa Diagram, Fishbone)

- Also called “Cause & Effect‟or „Ishikawa‟diagram
- Focus of Fishbone is to arrive at the root causes of the problem areas identified through multi-voting / process mapping
- Plug in Brainstorming session output in to the Fishbone Diagram using the 5M‟s and 1P. (Machine, Method, Material, Measurement, Mother Nature(or Environment) and Personnel.

Cause and Effect Analysis (Ishikawa Diagram, Fishbone)

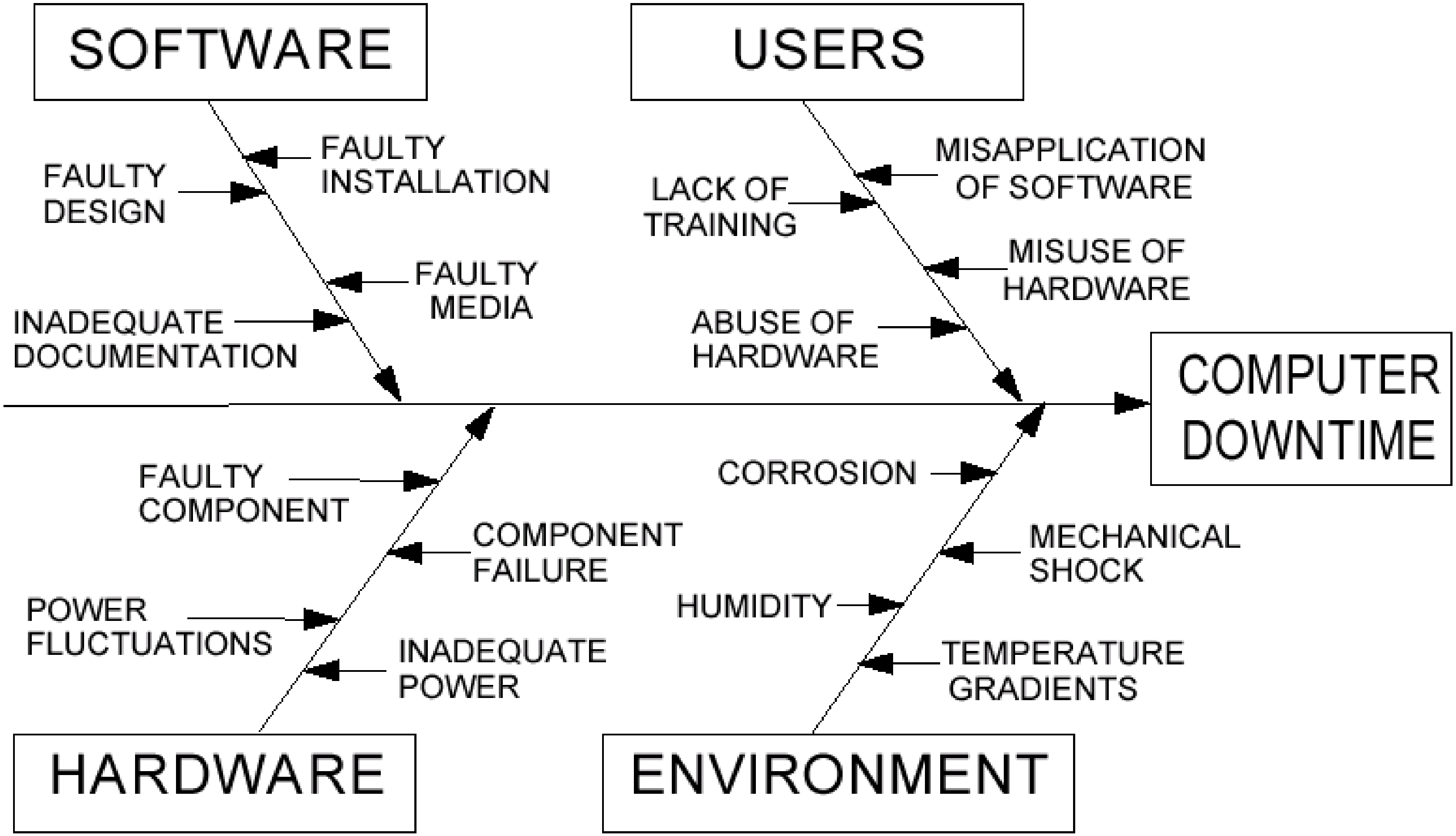


Example



METHODS
MACHINERY
PEOPLE
MATERIALS
POOR GAS MILEAGE
USE WRONG GEARS
POOR HEARING
RADIO TOO LOUD
CAN'T HEAR ENGINE
DRIVE TOO FAST
ALWAYS LATE
IMPATIENCE
FUEL MIX TOO RICH
NO RECORD OF TIRE PRESSURE
UNDERINFLATED TIRES
POOR DESIGN
MECH. DOESN'T KNOW CORRECT ADJUSTMENT PROCEDURES
DIFFICULT AIR STEMS
CARBURETOR ADJUSTMENT
POOR MAINTENANCE
$
NO AWARENESS
POOR TRAINING
"WHEN IN ROME"
POOR DRIVING HABITS
WRONG OCTANE GAS
NO OWNER'S MANUAL
DON'T KNOW RECOMMENDED OCTANE
NO OIL CHANGE
$
IMPROPER LUBRICATION
DON'T KNOW RIGHT OIL
WRONG OIL
NO OWNER'S MANUAL

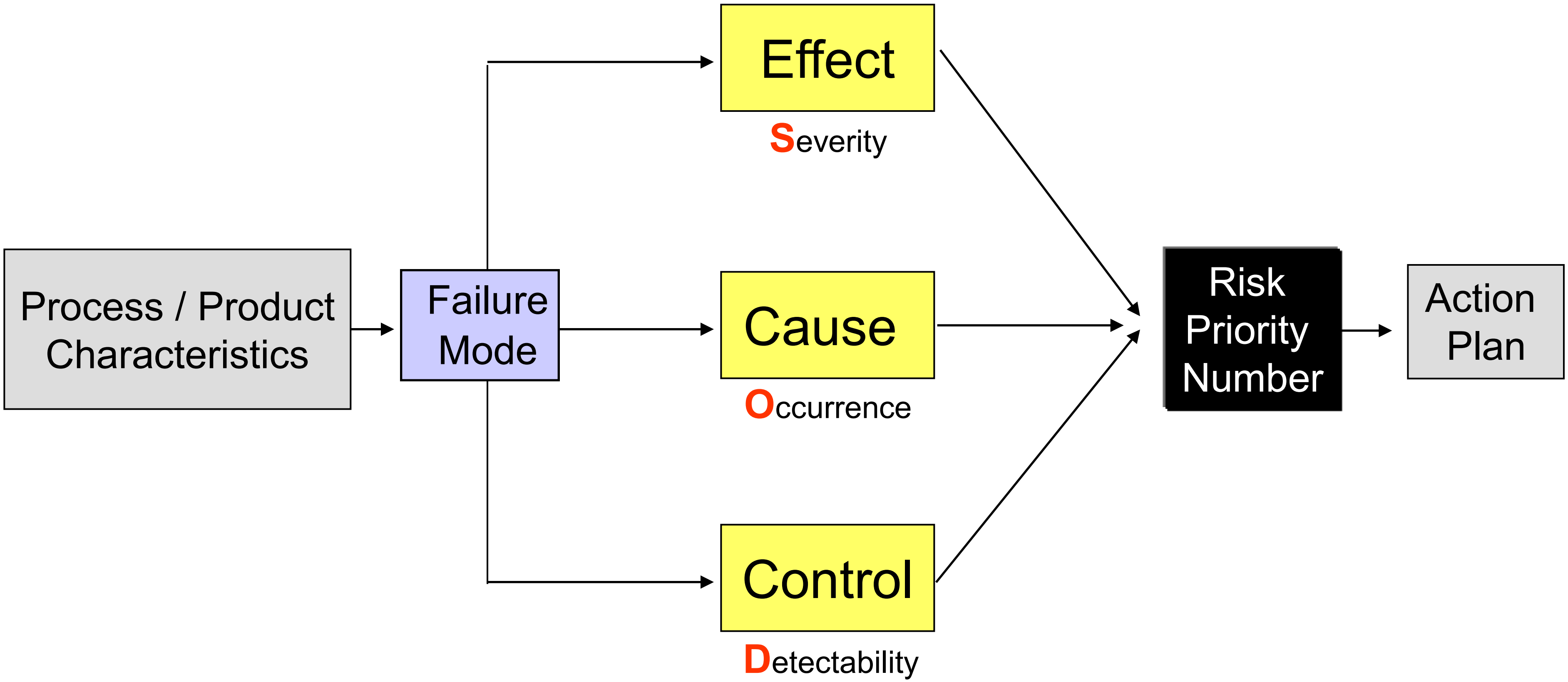
Example: Computer Downtime



Failure Mode & Effect Analysis (FMEA)

- FMEA is a simple tool to prioritize the failure modes & actions
- By understanding why and how we fail, we can plan for success
- It works on the belief that proactiveness saves time
- We shall focus on Process FMEA *(Design FMEA is used in designing products)*

FMEA Concept & Output



- Risk Priority Number (RPN) = S * O * D
- Severity, occurrence & detectability are measured on a scale of 1-9

FMEA Table

FMEA Table																
Process / Product Characteristics	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev (S)	Potential Cause(s) of Failure	Occ (O)	Current Design Controls	Det (D)	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	New Sev (S_N)	New Occ (O_N)	New Det (D_N)	New RPN (RPN_N)

FMEA - Definitions

- **Failure Mode:** The manner in which part/process can fail to meet specification. Usually associated with a defect or non – compliance
  - How can the process/ part fail to meet specifications?
  - What would a customer (End user, subsequent operations or service) consider objectionable - regardless of specifications?

- **Failure Effect:** Impact on customer if failure mode is not prevented or corrected. Customers can be downstream or end user
  - What are the consequences of the failure?

- **Cause:** A deficiency that results in a failure mode.
  - Causes are sources of variability associated with key process input variables (KPIV).
  - Causes are described in terms of something that can be corrected or can be controlled.

Steps in creation of Process FMEA

1. List the process steps and their associated Xs.

2. For the X, list all the ways that the X can fail, known as Failure Modes
   - The most common mistake here is to list *why* it would fail as opposed to *how*
   - Example of Failure Modes for *any* X are
     i. X is too high (*excess amount entered in invoice*)
     ii. X is too low (*less amount entered in invoice*)
     iii. X is intermittent/variable (*inconsistent amount entries in invoices*)
     iv. X is missing (*amount not entered in invoice*)

   - **Any X can have multiple Failure Modes and each must be dealt with separately by adding additional rows in the FMEA**

Steps in creation of Process FMEA (cont)

3. For each Failure Mode, list the Effects that the Failure Mode would have on the downstream Customer(s)
   - These can remain grouped in one cell in the spreadsheet as you consider them as a whole and focus on the worst case of them as you proceed (i.e. don't create additional rows in the worksheet at this stage)

4. For each Failure Mode, list the Cause of the Failure Mode.
   - Each Failure Mode can have multiple Causes
   - Unlike the Effects column, the Causes are all dealt with separately, and an individual row should be created for each Cause
   - The Cause is the "why" the Failure Mode occurs

- At this point we have a three step causal chain: the **Cause**, which causes the **Failure Mode**, which in turn causes the **Effect**

Steps in creation of FMEA (cont)

5. For each individual Cause, list the *current* set of Controls for the causal chain: Cause -> Failure Mode -> Effect
    - Be specific about the Controls

6. The Severity, Occurrence, and Detection rates are scored based on a scoring matrix

7. For **each Failure Mode** score the **severity of the *worst case*** of the list of effects associated with the Failure Mode as per the scoring table

8. For **each Cause** (usually multiple per Failure Mode), rate the **likelihood of occurrence** as per the scoring table

9. For each **Control group** (one group per Cause) list the **detection rate** of the combined group of Controls

FMEA Definitions

- **Risk Priority number (RPN)**
  - The output of an FMEA is the "Risk priority Number” (RPN)
  - RPN is a calculated number based on information you provide regarding the potential failure modes, the effect and the current ability of the process to detect the failures before reaching the customer

  - It is calculated as the product of three quantitative ratings, each one related to the effects, causes and controls

RPN = Severity X Occurrence X Detection

Effects X Causes X Controls

FMEA - Definitions

- **Risk Priority Number, RPN Terms**
  - **Severity (of effect)**
    - Importance of effect on customer requirement.
    - Could also be concerned with safety and other risks if failure occurs.
  - **Occurrence (of cause)**
    - Frequency with which a given cause occurs and creates failure mode
  - **Detection (Capability of current controls)**
    - Ability of current control scheme to detect

- The causes before creating failure mode
- The failure modes before causing effect
- All three use a scale of 1-10, with 1 being best or lowest risk,10 being worst or highest risk

FMEA Definitions

- **Current Controls:**
  - The mechanism that prevent or detect the failure mode before it reaches the customer.
  - Current controls include SPC, Inspections, Monitoring, Training, Preventive Maintenance

- **Recommended action:** Corrective actions to reduce occurrence, and/or detection ratings.
  - Directed at the highest RPN and critical severity items.

  - **Focus is usually in the order**
    1. **Detection (Controls) first, then**
    2. **Occurrence, then**
    3. **Severity**

FMEA Rating Scale (sample guidelines)

Rating	Severity of Effect	Likelihood of Occurrence	Ability to Detect
10	Lose Customer	Very high: Failure is almost inevitable	Cannot detect
9	Serious Impact on customer's business or process		Very remote chance of detection
8	Major inconvenience to customer	High: Repeatable Failures	Remote chance of detection
7	Major defect noticed by most customers		Very low chance of detection
6	Major defect noticed by some customers	Moderate: Occasional Failures	Low chance of detection
5	Major defect noticed by discriminating customers		Moderate chance of detection
4	Minor defect noticed by most customers		Moderately high chance of detection
3	Minor defect noticed by some customers	Low: Relatively few Failures	High chance of detection
2	Minor defect noticed by discriminating customers		Very high chance of detection
1	No effect	Remote: Failure is unlikely	Almost certain detection

FMEA (Failure Mode Effect Analysis) – Another example

Severity Scale : The consequence should a failure occur

Rating		Guideline
10	Bad	Cause injury
9		Lead to compliance issue or legal issue
8		Render the product or service unfit for use
7		Causes extreme dissatisfaction
6		Partial malfunction of product or service
5		Cause a loss of performance leading to complaint
4		Causes minot performance loss
3		Small irritant witrh no loss of performance
2		Unnoticed with minor effect on performance
1	good	Unnoticed and no effect on performance

FMEA (Failure Mode Effect Analysis) - Another example

Occurence Scale : Frequency of Failure

Rating		Duration	Probability Scale
10	Bad	More than once a day	>30%
9		Once every 3-4 days	<= 30%
8		Once per week	<=5%
7		Once a month	<=1%
6		Once every 3 months	<=0.03%
5		Once every 6 months	<= 10 per lakh
4		Once a year	<= 6 per lakh
3		Once every 1-3 years	<=6 per Million
2		Once every 3-6 years	<=3 per 10 Million
1	Good	Once every 6- 100 years	<=2 per billion

FMEA (Failure Mode Effect Analysis) - Another example

Detection Scale: probability of a failure being detected

Rating		Guideline
10	Bad	Defect caused by failure goes undetected
9		Occasional units checked for defects
8		Units are systematically sampled and checked
7		All units are manually inspected
6		Units manually inspected with mistake proofing modifications
5		Process is monitored and manually inspected
4		SPC used with instant reaction to out of control condition
3		PC as above coupled with 100% inspection of surrounding out of control condition
2		All units automatically inspected
1	Good	Obvious defect and is prevented from reaching the customer

FMEA Example

FMEA Table																
Process / Product Characteristics	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev (S)	Potential Cause(s) of Failure	Occ (O)	Current Design Controls	Det (D)	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	New Sev (S_N)	New Occ (O_N)	New Det (D_N)	New RPN (RPN_N)
Playing a cricket match	Losing	Loss of money	9	Lack of fitness	9	Fitness report from any doctor	3	243	Panel of certified doctors	Management	2 doctors have been nominated to certify fitness	9	7	1	63
				Betting	7	None	9	567	Audit bank accounts of players, control external interaction	Management	Audit procedure has been designed		5	5	225
				Lopsided team due to bias	5	Selection committee selects	5	225							

Repeat the same exercise for another failure mode – *match abandoned*

FMEA Template

Pizza Delivery

Process Step	Failure Mode	Effect	Severity	Cause	Occurrence	Current Controls	Detection	RPN
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
Baking	Over Baked	Pizza not fit for eating (does not endanger customer safety)	8	Baked for more time (1/100 * 2/100) = 1/500	5	Baked Pizza is compared with sample	7	280
				Baked at Over Temperature (1/100 * 8/10) = 1/125	6			
	Under Baked	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

FMEA Template

Pizza Delivery

Process Step	Failure Mode	Effect	Severity	Cause	Occurrence	Current Controls	Detection	RPN
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
Baking	Over Baked	Pizza not fit for eating (does not endanger customer safety)	8	Baked for more time (1/100 * 2/100) = 1/500	5	Buzzer for Overtime	4	160
				Baked at Over Temperature (1/100 * 8/10) = 1/125	6			
	Under Baked	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

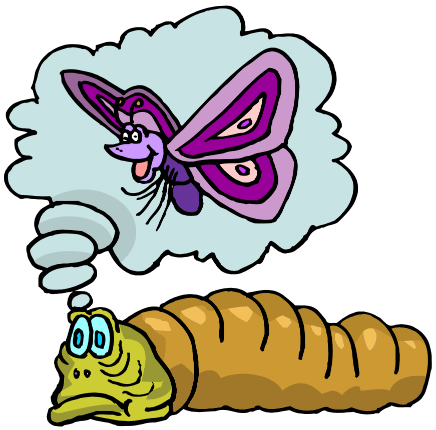
FMEA Template

Pizza Delivery

Process Step	Failure Mode	Effect	Severity	Cause	Occurrence	Current Controls	Detection	RPN
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
Baking	Over Baked	Pizza not fit for eating (does not endanger customer safety)	8	Baked for more time (1/100 * 2/100) = 1/500	2	Auto Ejector at Required Time with detection against sample	7	112
				Baked at Over Temperature (1/100 * 8/10) = 1/125	6			
	Under Baked	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

Lean Thinking

A <u>principle</u> driven, <u>tool</u> based philosophy that focuses on eliminating <u>waste</u> so that all activities/steps add <u>value</u> from the <u>customers</u> perspective.



Imagine Office Processes with:

- Higher Customer Satisfaction
- Shorter Lead Time
- Higher Flexibility
- Higher Quality
- Lower Costs
- Higher Employee Satisfaction

Organizational Challenge

The challenge is to make

- what the customer wants,
- when the customer wants it,
- at a price the customer is willing to pay.

What is Lean?

- ✓ Learning to see waste
- ✓ Eliminating waste by
- ✓ Continuously Improving everything

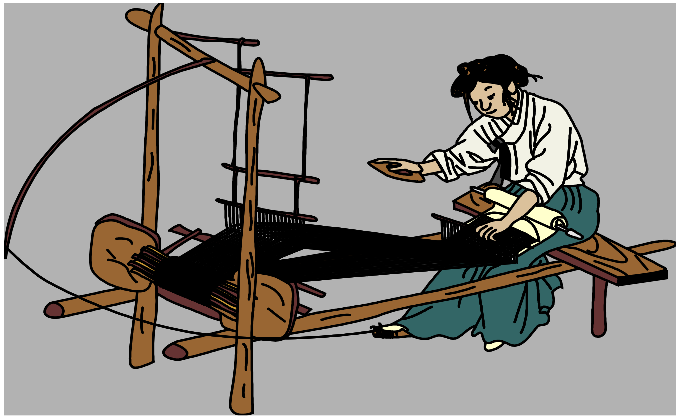
PERCEPTION Vs ACTUAL WORK

How long does it take to:

Change a wheel in a Car	15 mins	7 Secs
Win a Wimbledon Final Match	2.5 hours	3 mins
Manufacture a sports shoe	8 hours	30 mins

Lean is all about finding & removing the waste

Lean at Toyota – How it Started?

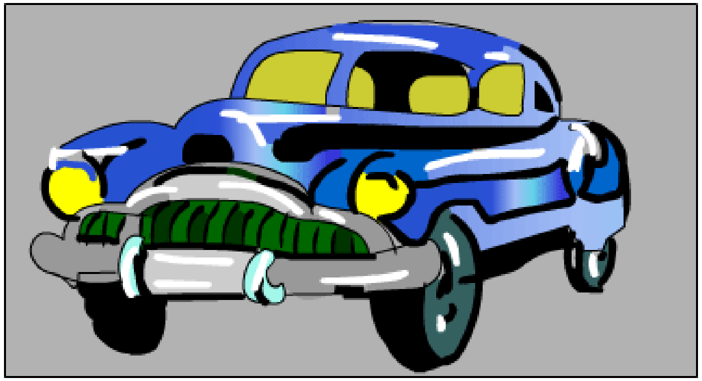


1902

Sakichi Toyoda, founder of the Toyota group, invented an automated loom that stopped anytime a thread broke.

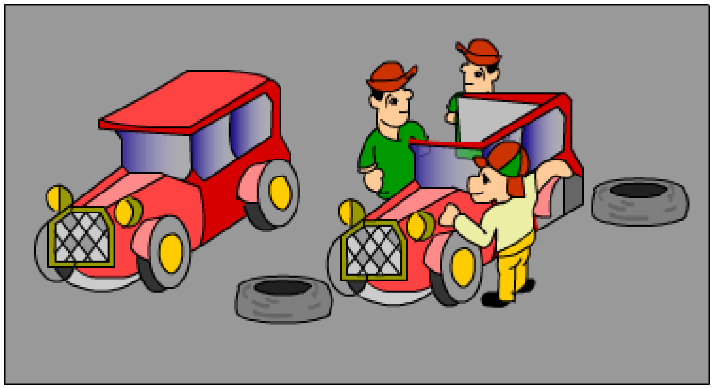
1937

Toyota Motor Company Ltd. is created from the Toyoda Automatic Loom Works.



Foundation

Lean at Ford - 1908

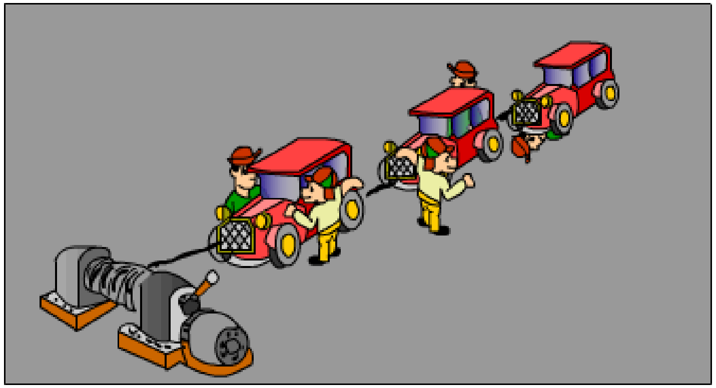


Before

Cars were built in one spot and the workers moved from car to car. This was called the „gypsy production" system.

After

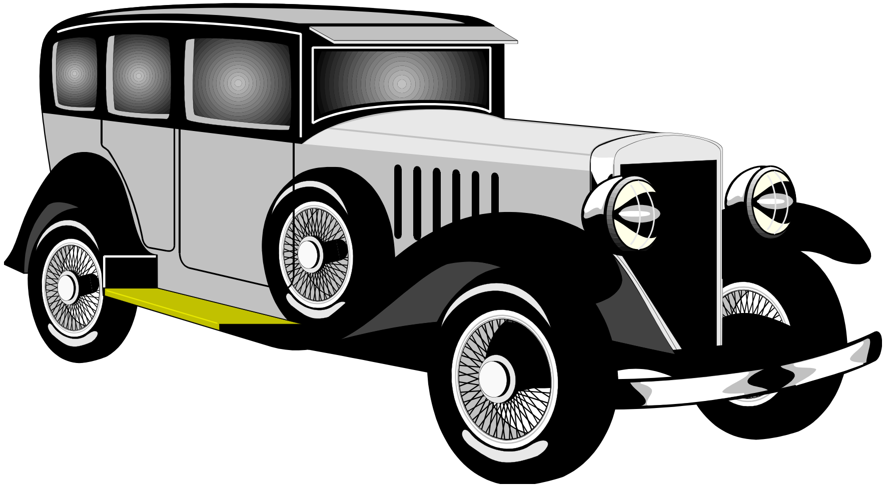
Ford used a big rope and winch to pull the cars along the assembly line and kept the workers stationary.



Organizational Challenge

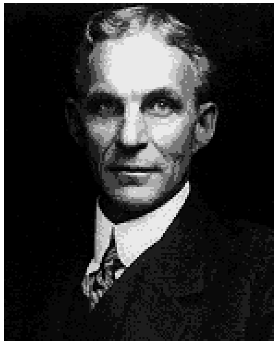
CRAFT MANUFACTURING - Late 1800's

- Car built by workers who walked around the car
- Built by craftsmen with pride
- Components hand-crafted, hand-fitted
- Excellent quality
- Very expensive
- Few produced

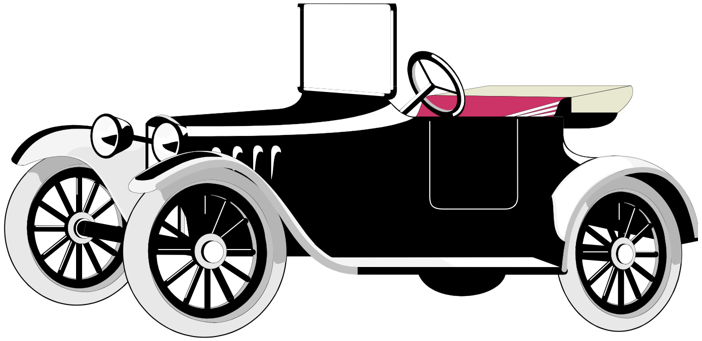


Organizational Challenge

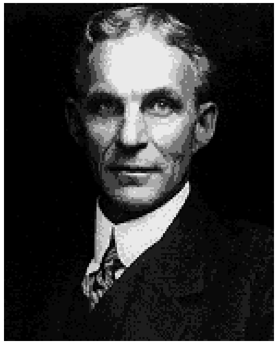
Starting about 1910, ***Ford and his right-hand-man, Charles E. Sorensen, fashioned the first comprehensive Manufacturing Strategy.***



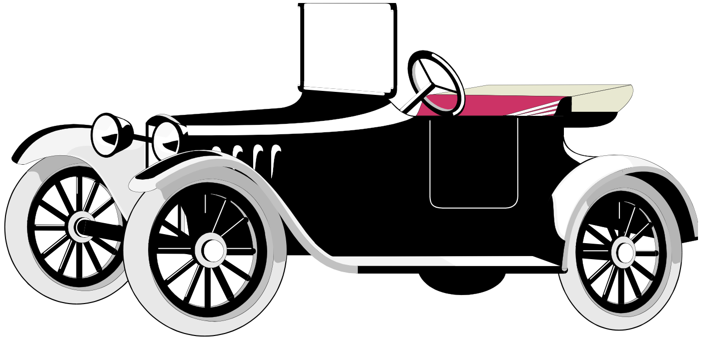
They took all the elements of a manufacturing system-- people, machines, tooling, and products-- and arranged them in a continuous system for manufacturing the Model T automobile.



Organizational Challenge



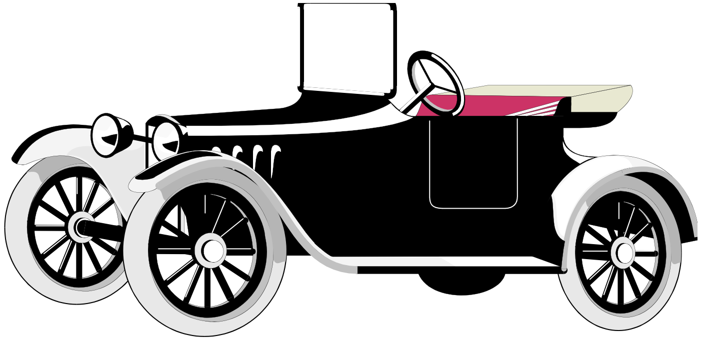
Ford is considered by many to be the first practitioner of Just In Time and Lean Manufacturing.



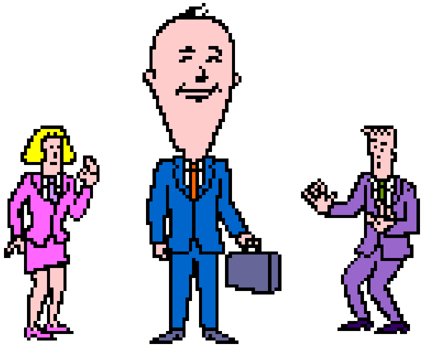
Organizational Challenge

Assembly line - Henry Ford

- Low skilled labor, simplistic jobs, no pride in work
- Interchangeable parts
- Affordably priced for the average family
- Millions produced - identical



Customer Expectation

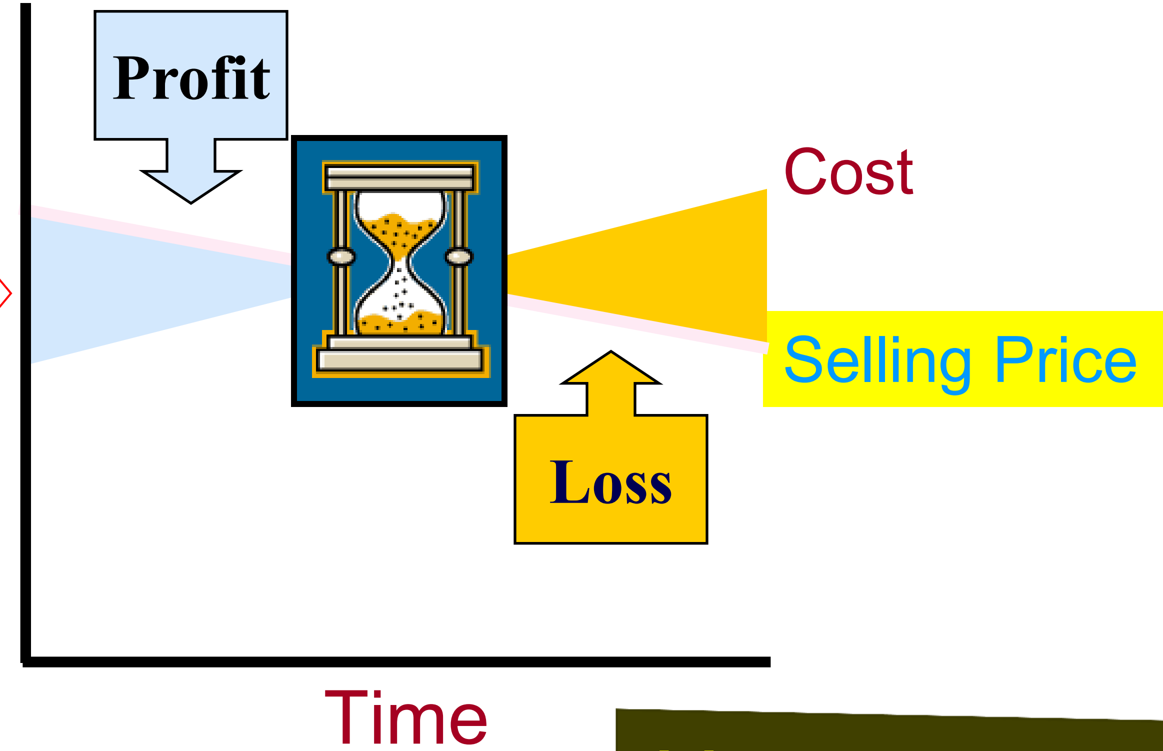


- Much better quality
- More customized variants
- Just-in-time delivery
- Shorter lead times
- And freedom to order in small quantities

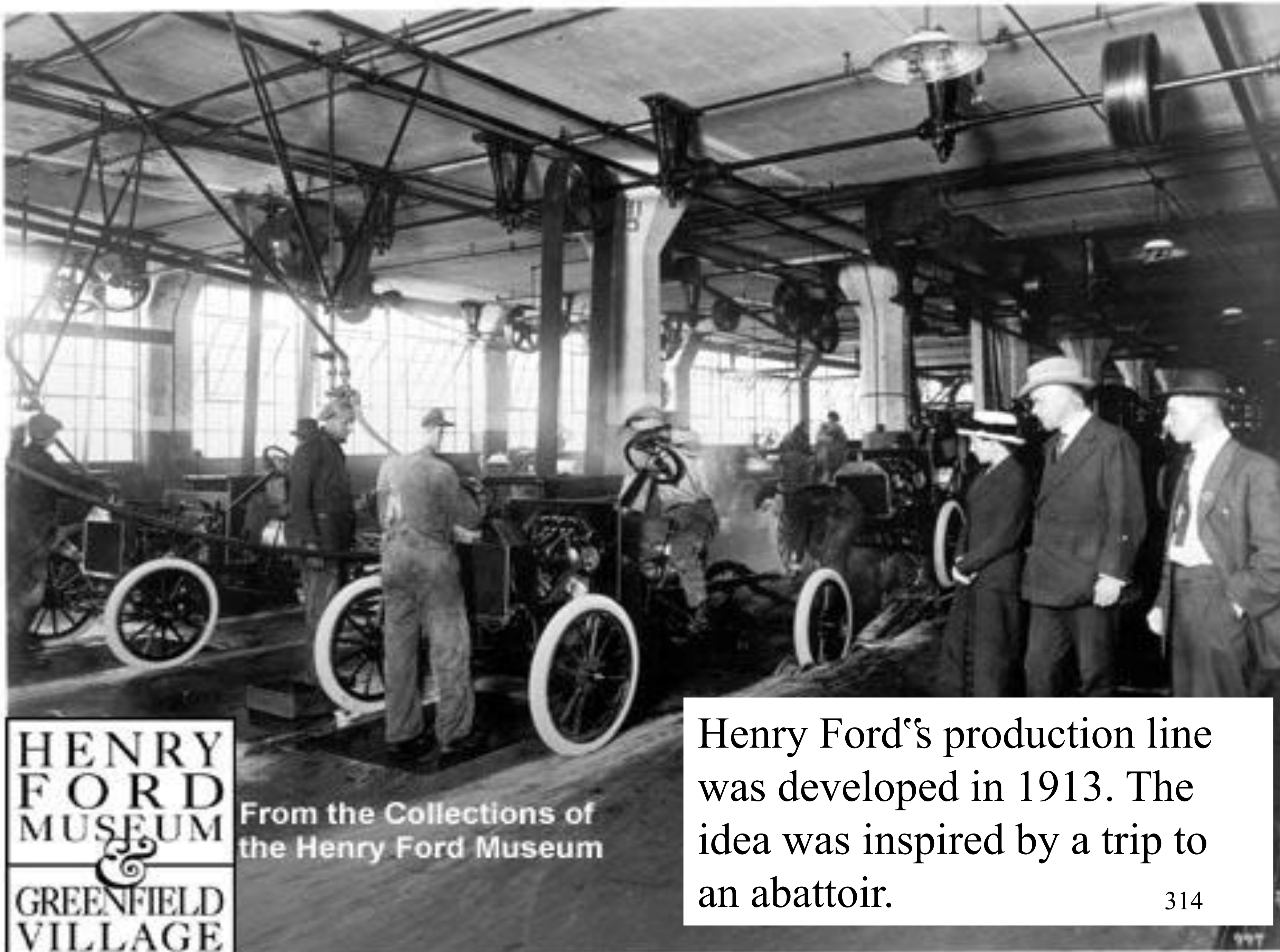
…..At Lower & Lower Prices

Cost Vs. Selling Price

DON'T WAIT...
NOW IS THE
TIME



How to survive?



Henry Ford‘s production line was developed in 1913. The idea was inspired by a trip to an abattoir.


1909 Model T Ford
Any colour you like provided it is black!
Ford
SG 6552
C 27


CARS
DJR 884
Ford

Scientific Management

“Whenever a workman proposes an improvement, it should be the policy of the management to make a careful analysis of the new method, and if necessary conduct a series of experiments to determine accurately the relative merit of the new suggestion and of the old standard. And whenever the new method is found to be markedly superior to the old, it should be adopted as the standard for the whole establishment“, F.W.Taylor, Principles of Scientific Management, 1911.

Standardisation and best practice deployment

How to Survive?

- During 1970s, Japanese were redefining the manufacturing paradigms.
- Began to incorporate quality
  - into **cost focused strategy**
- Discovered the power of **FLOW**
  - Use of TIME as a new competitive dimension

Toyota Production System was born

Toyota Production System

- After World War II, Toyota was almost bankrupt.
- Post war demand was low and minimising the cost per unit through economies of scale was inappropriate. This led to the development of demand-led pull systems.
- The Japanese could not afford the expensive mass production facilities of the type used in the USA so they instead focused on reducing waste and low cost automation.
- Likewise, Toyota could not afford to maintain high inventory levels.

Founders of the Toyota Production System (TPS)

Taiichi Ohno
(1912 †1990)

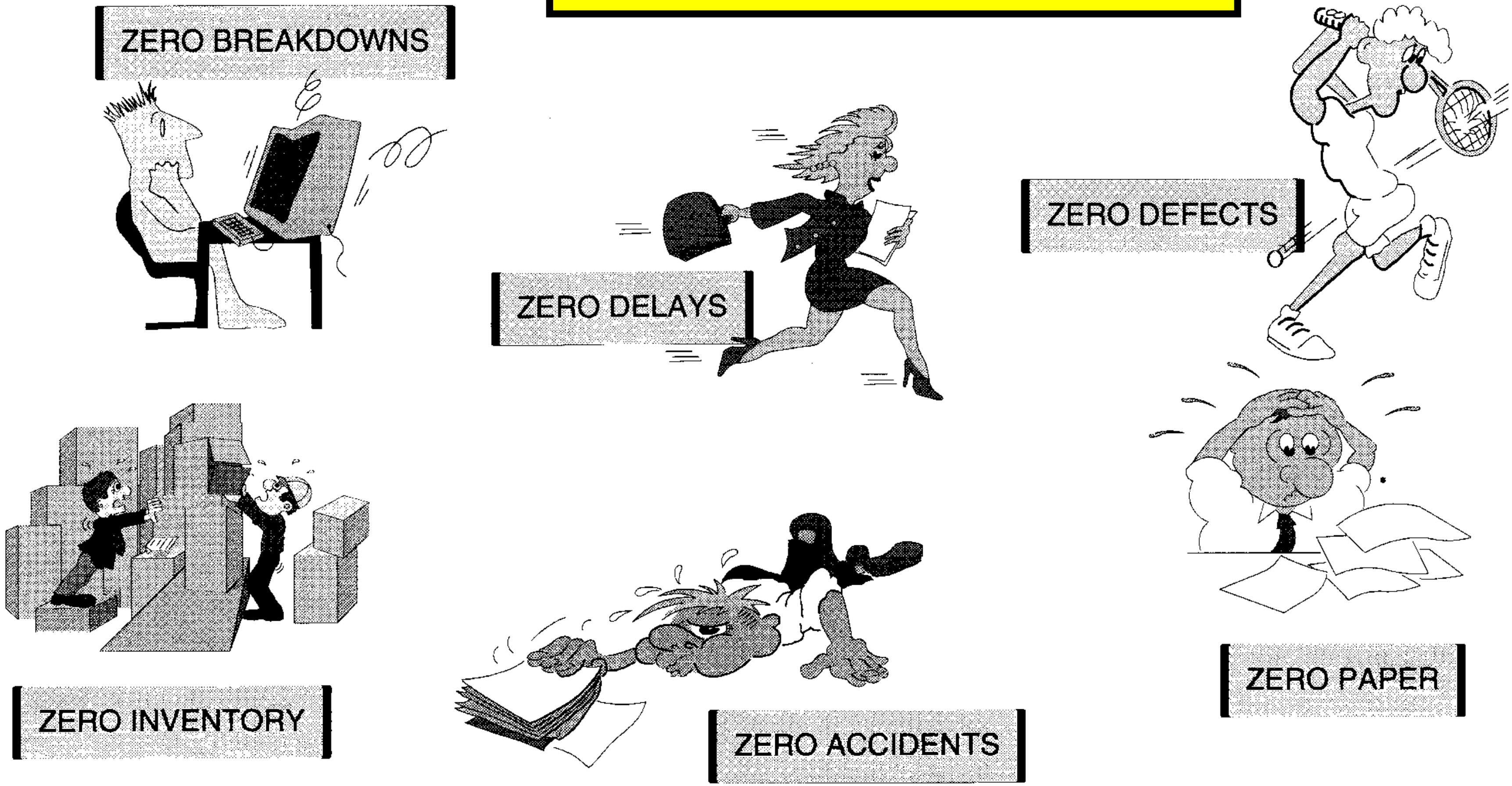
Shigeo Shingo
1909 †1990

Just-in-Time Manufacturing

"In the broad sense, an approach to achieving excellence in a manufacturing company based upon the continuing elimination of waste (waste being considered as those things which do not add value to the product). In the narrow sense, JIT refers to the movement of material at the necessary time. The implication is that each operation is closely synchronised with subsequent ones to make that possible"

JIT became part of Lean Manufacturing after the publication of Womack's Machine that Changed the World in 1991

Lean Manufacturing goals



Waller, D.L.,,1999,"Operations Management: A Supply Chain Approach", (Thompson, London)

Lean Manufacturing

- Arose in Toyota Japan as the Toyota Production System
- Replacing complexity with simplicity
- A *philosophy,* a way of thinking
- A process of *continuous* improvement
- Emphasis on minimising inventory
- Focuses on eliminating waste, that is anything that adds cost without adding value
- Often a pragmatic choice of techniques is used

Toyota Production System

- Technologies and practices can be copied.
- However, Toyota remains at the forefront, primarily because it is a learning organisation.
- Problem solving methods are applied routinely and are completely ingrained.
- The employees are continually engaged in *Kaizen* (continuous improvement).
- Many aspects of TPS are based upon embedded tacit knowledge.

What if Flow is not proper?

- Traffic jam
- Trains/ flight not on time
- Blood pressure
- Heart attack
- Flood/ draught
- High Inventory
- High lead time
- Increased cost

What else…

Taiichi Ohno …

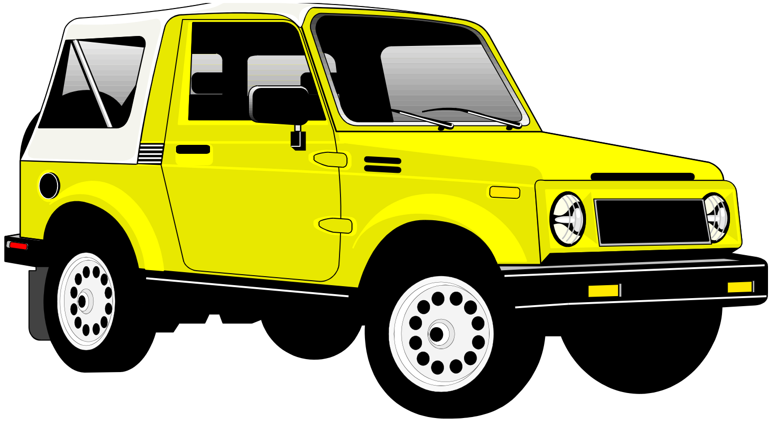
All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash.

And we are reducing that time line by removing the non-value added wastes.

Taiichi Ohno, 1988

Toyota Management

- Cells or flexible assembly lines
- Broader jobs, highly skilled workers, proud of product
- Low lead time
- Excellent quality mandatory
- Costs being decreased through process improvement.
- Global markets and competition



Lean Management

- During 1980s Americans realized that the things are not the same anymore.
- Japanese were not only making better cars, they were also doing it cheaply.
- Toyota was making cars in America at 25% less cost.
- Severely denting American market share.

Lean Management Philosophy

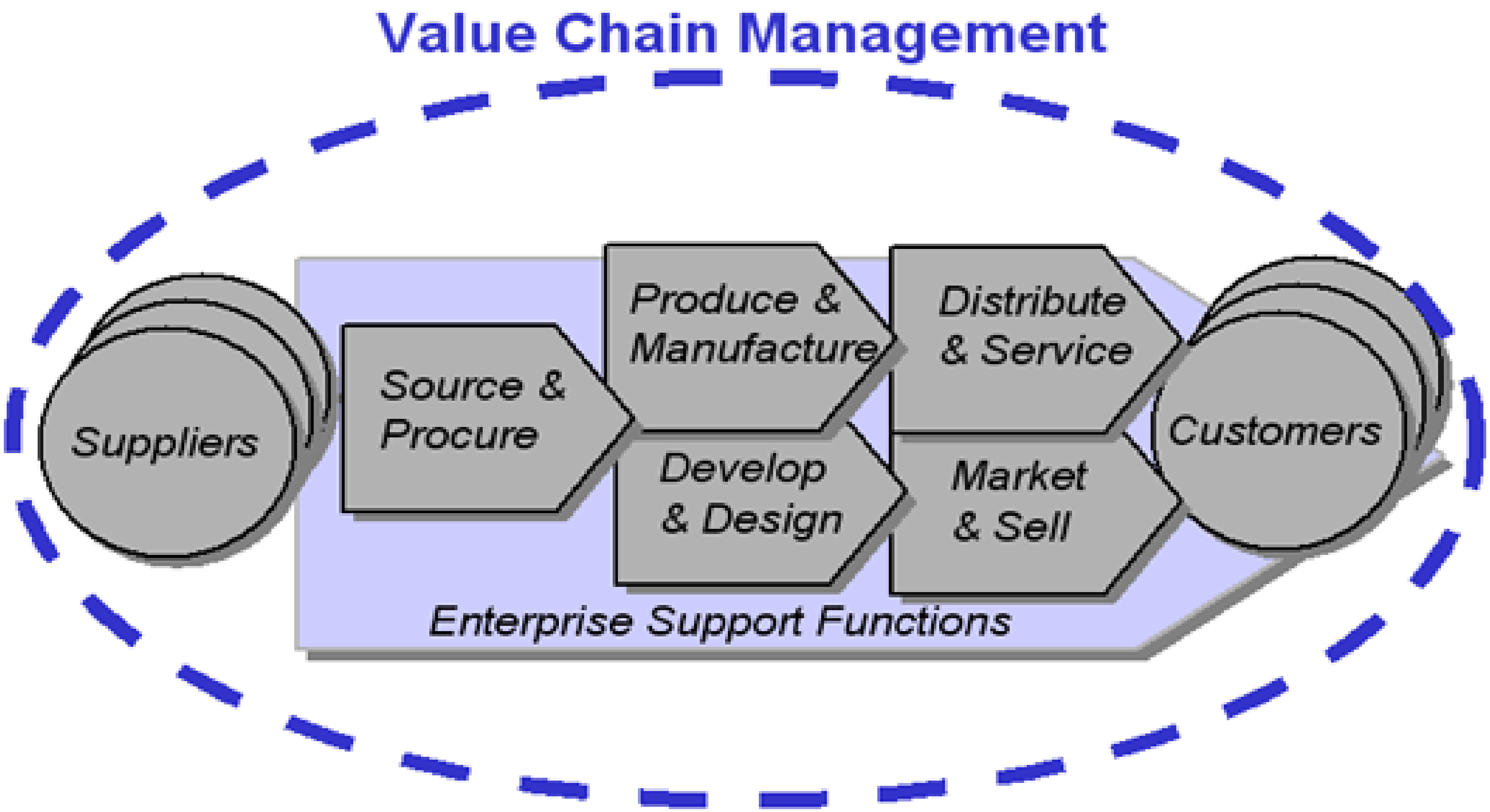
An outcome of study of Toyota Production Systems, by a team of researchers in USA, led by James Womack & Daniel Jones.

Their books detailing how Toyota has emerged, as the world's most efficient automaker popularized Lean Manufacturing as a new manufacturing philosophy.

The first book was published in 1990 as

"The Machine That Changed the World"

Covers Transformation of the Entire Value Chain



"Creating the Roadmap for the Future"

The Underlying Premise of Lean

"Time to Cash"

Traditional

Customer Order → Waste → Product Delivery

Time in Value Stream, "Lead Time"

Lean

Customer Order → ~~Waste~~ → Product Delivery

Time in Value Stream, "Lead Time"

✓ **Speed**
✓ **Cost**

A relentless focus on reducing Lead time to reduce costs
. . . by driving out WASTE and SPEEDING up the process

- Let customers say what is of value to them
- Reduce non-value adding activities in the system, causing process speed to increase
- Faster process speed positively relates to less waste, less cost, less work in process (WIP), less complexity, higher quality and happier customers
- Work to eliminate the root causes of the waste and allow for one-piece, continuous flow

VALUE:

- An activity that transforms or shapes raw material or information to meet customer needs

WASTE:

- Activities that consume time, resources and space, but do not contribute to satisfying customers needs

Customers will pay for value…
they will not pay for waste

What is Value addition?

Any activity that qualifies following 3 criteria:

1. There should be some form of change.
2. It should be done right the first time.
3. Customer should be ready to pay for it.

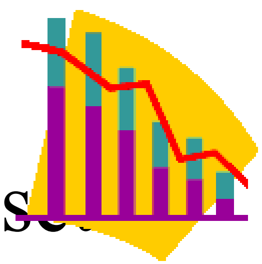
Let us find out how lean has been developed.

Value

- That customer is willing to pay
- That changes products color, function, shape, other attributes so that the product is getting closer to the customers requirements
- That we do right at first time

Wastes

- Those processes which directly do not create value for customers (muda, mura, muri) :
  - that are not necessary, and must be eliminated
  - *That are necessary, because these are supporting value-add processes, cannot be eliminated (like transporting)*
- *Muda – 8 wastes of lean*
- *Mura* – not leveled workflow
- *Muri* – overloading of workers and ass

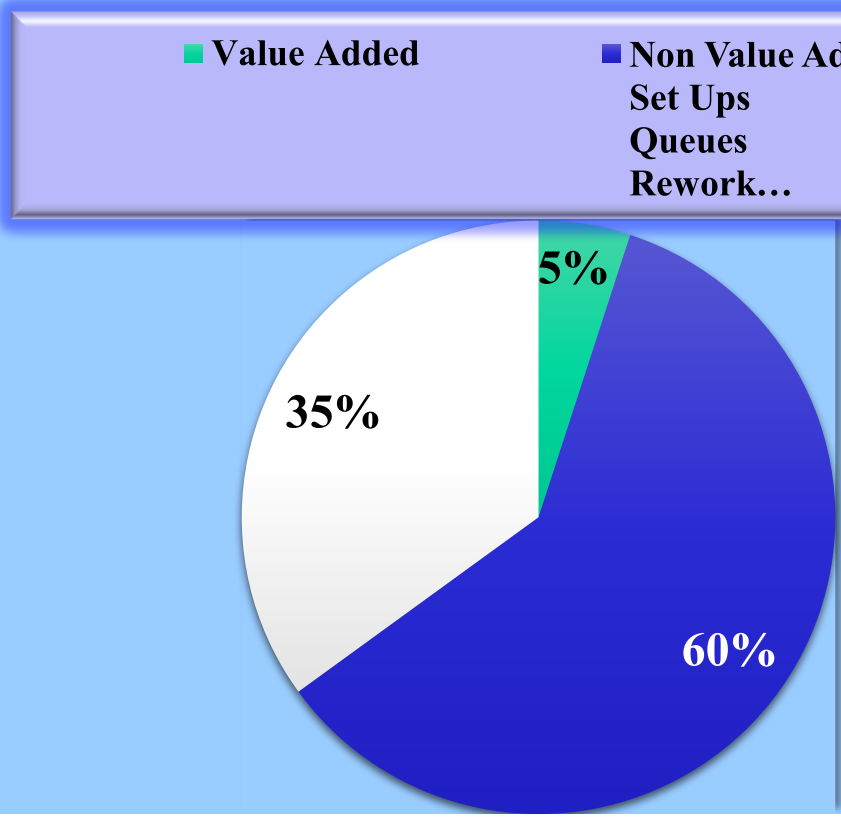


Value Added Time & Activity

- **Value** added is the amount by which the dollar/rupee value of a product (including raw materials and minerals) increases as it proceeds through the various stages of its processing, manufacturing and distribution.
- **Value added time** is time directly spent on increasing the value of a product (including raw materials and minerals) as it proceeds through the various stages of its processing, manufacturing and distribution.
- **Value added activities** are those actions efficiently, effectively, and directly related to increasing the value of a product (including raw material and minerals) as it proceeds through the various stages of its processing, manufacturing and distribution.

VA/NVA

VA / NVA - Process Time



In many manufacturing processes up to 95% of the process time can attribute to NVA activity.

NVA examples

- Waiting for materials to be brought to production/processing work centers
- Time spent doing personal work on the computer and on personal phone calls
- Spending time searching for materials, tools, supplies, information, etc. that are not in their proper location
- Arriving at the work center late and leaving the work center early
- Maintenance employees making numerous trips to get the right repair parts and tools
- Attending a training session and never using/or be allowed to use the information/skills presented

NVA examples

- Knowingly producing "off spec" product just to make the production goal
- Equipment failures (computer systems to the behemoth draglines) causing idle time
- Bottlenecks of all sorts (mining, manufacturing, distribution, administration, etc.) that create dead time
- Waiting for approvals or direction from leadership
- Waiting for assistance from various support functions
- Correcting inaccurate information provided by others (e.g., time cards, production reports, purchase requisitions, inventory levels, budgets)

VA/NVA Exercise

Segregate the following into VA & NVA

- Entering orders
- Waiting for parts
- Recording
- Moving WIP
- Testing
- Kitting/staging
- Reviewing
- Inspection
- Assembling products
- Counting Parts
- Copying reports
- Filling information
- Revise/reworking
- Tracking WIP
- Ordering Raw material
- Shipping to customers
- Fuelling delivery trucks
- Preparing Engineering drawings
- Obtaining multiple approvals
- Processing customer deposits
- Selling concert tickets
- Examining patients
- Checking
- Filing Insurance claims

VA	NVA
•Entering orders	•Reviewing
•Ordering Raw materials	•Inspection
•Shipping to customers	•Waiting for parts
•Assembling products	•Recording
•Preparing Engineering drawings	•Copying reports
•Fuelling delivery trucks	•Counting parts
•Examining patient	•Moving WIP
•Processing customer deposits	•Testing
•Filling insurance claims	•Filing information
•Selling concert tickets	•Obtaining multiple approvals
	•Revising/Reworking
	•Checking
	•Tracking WIP
	•Kitting/staging

VA/NVA Exercise

- Write your workplace VA/NVA & present.

What is Value addition?

Any activity that qualifies following 3 criteria:

1. There should be some form of change.
2. It should be done right the first time.
3. Customer should be ready to pay for it.

Let us find out how lean has been developed.

TOTAL, BASIC & ADDED WORK CONTENT

TOTAL = BASIC + ADDED + IDLE TIME

Basic work content is the irreducible minimum time of performance. It is hardly achievable.

Added work content is time added due to either improper method or due to improper design of the product.

Idle time is when the man & m/c are both inactive. It may happen due to workers or management both.

Lean Vs Mass Production

Conventional Thinking	Lean
Produce as Much as possible	*Produce only what the customer needs*
Productivity = Utilization	*Productivity = Through put*
Produce Large batches	*Small batches, single piece where possible*
Extensive set up change batch to batch	*Single minute set up change*
Purchase large Economic order quantities	*Purchase small lots just when needed*
Line stoppage = loss of productivity	*line stoppage at abnormality fixes issues quicker… and deliver more!*

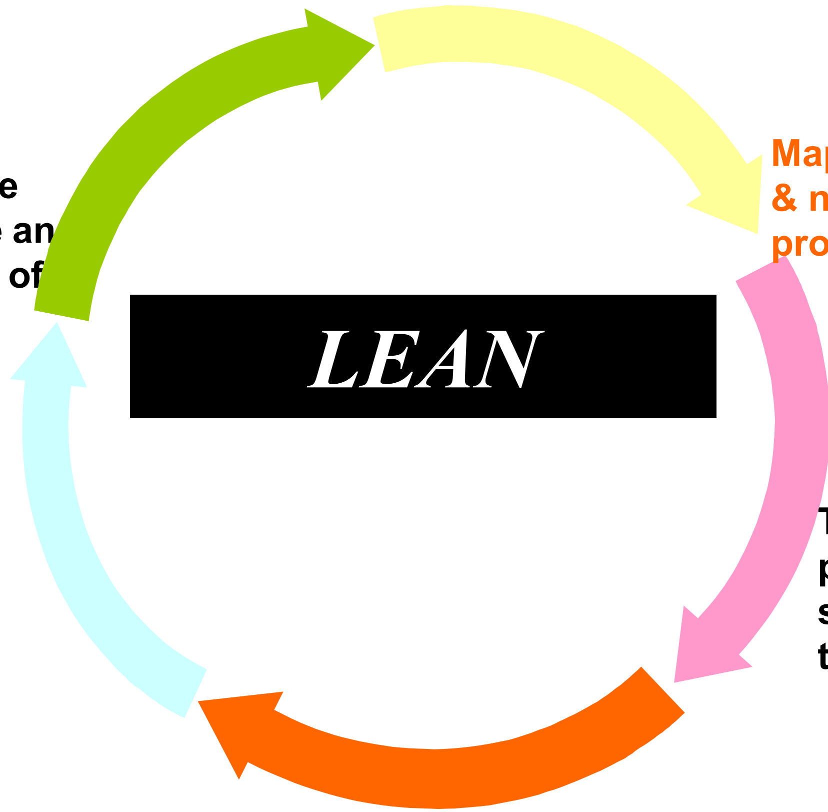
Stage Lean Approach

1: Identify Value

Define value in from the customers perspective and express value in terms of specific processes

2: Map the Value Stream

Map all of the steps… value added & non-value added… that bring a product or service to the customer



3: Establish Flow

The continuous movement of products, services & information smoothly end-to-end throughout the process

4: Establish Pull

Nothing is done by the upstream process until the downstream customer signals the need

5: Pursue Perfection

Complete elimination of waste so all activities create value for the customer

Lean Thinking

The Five Components:

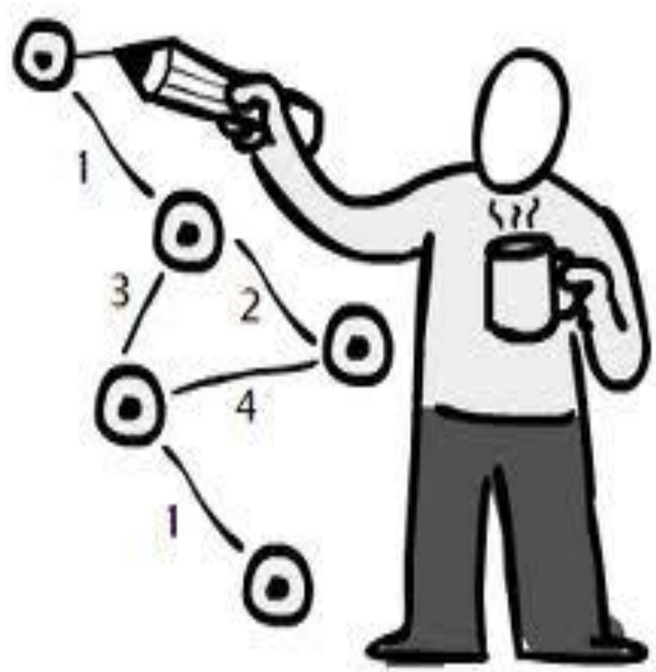
1. Specify Value from the end customer's perspective.
2. Identify the Value Stream for each product family and remove waste.
3. Make the Product Flow through the Value Stream.
4. So that customer can Pull from the producer.
5. Constantly pursue Perfection.

Value

- Define Customer : clearly understand who the customer is.
- Define Value : Quality, schedule, target cost etc.
- Ask how your current products and processes dissatisfy your customers value expectations,
    - Price?
    - Quality?
    - Reliable Delivery?
    - Rapid response to changes?

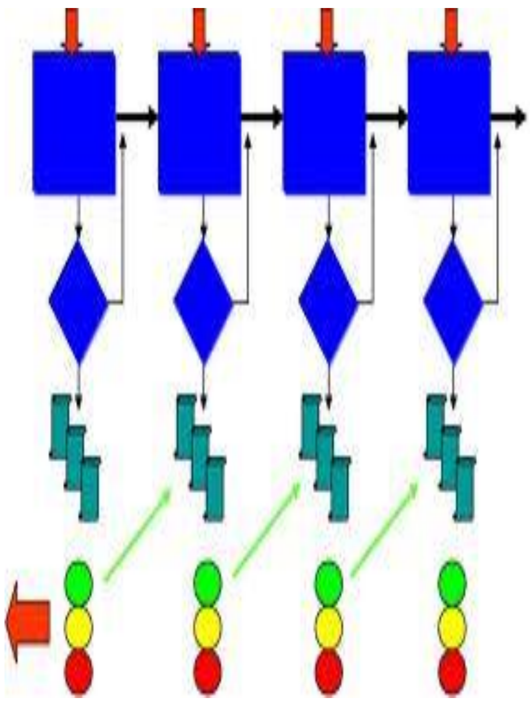
Value Stream

- Lean Management is an end-to-end collection of processes that create value for the customer
- The value stream includes
  - People
  - Tools and technologies
  - Physical facilities
  - Communication channels
  - Policies and procedures



Value Stream

Identify all of the steps currently required to move products from order to delivery :



- Challenge every step: why is this necessary? What does the customer think?
- Critically assess value addition at each step.
- Eliminate / minimize non-value-added activities.

Tip : Use Value Stream Mapping Tool

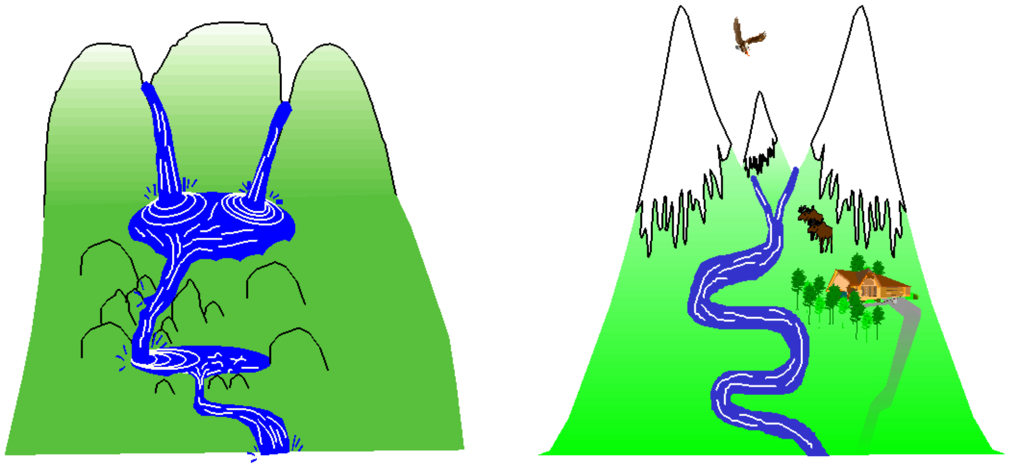
Flow

Line-up all the steps that truly create value so they occur in rapid sequence;

- Produce each product, everyday, in direct proportion to demand.
- Require that each step in the process be,
  - Capable , right every time (SIX SIGMA)
  - Available, always able to run (TPM)
  - Adequate, with capacity to avoid bottleneck. (right size tooling).

Flow

- "Flow" refers to the movement of material through the plant.
- The material should not be stagnant at any point in time from the receiving of raw material to the shipping of finished products.

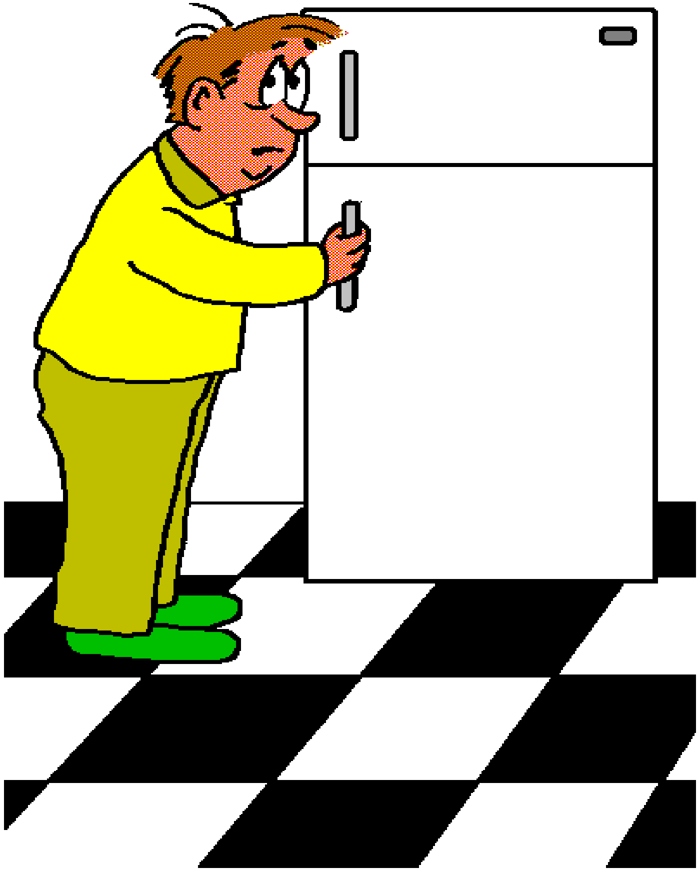


Pull

Customer should Pull value through the Value Stream;

- Through lead time reduction & correct value specification, let customers get exactly what they want & exactly when they want.

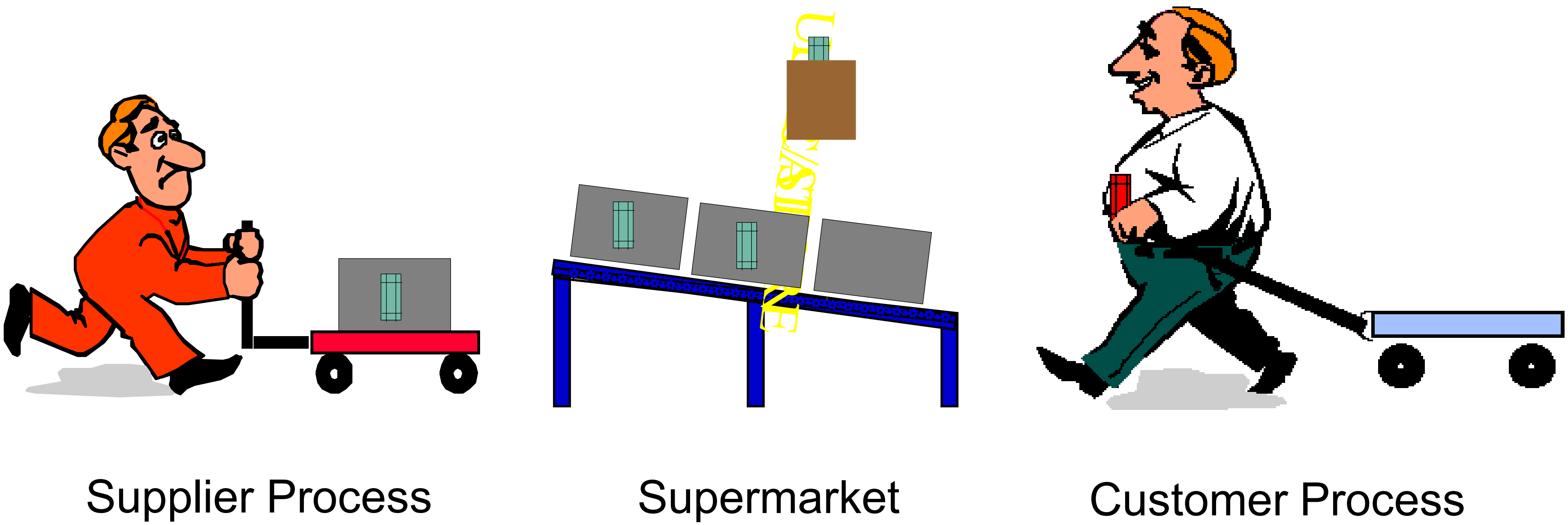
Pull System



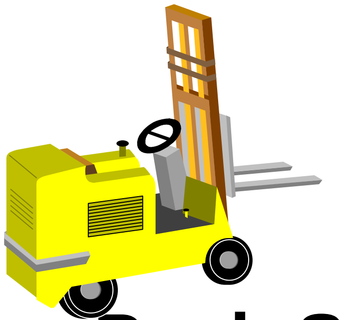
A method of controlling the flow of resources by replacing what has been consumed.

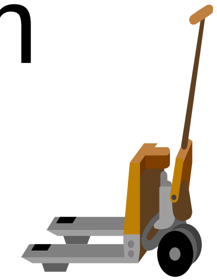
Pull System

A method of controlling the flow of resources by replacing what has been consumed



Push Vs. Pull System





Push System

- Large Lots
- Hidden Problems
- Waste
- Poor Communication
- Approximation/Forecast

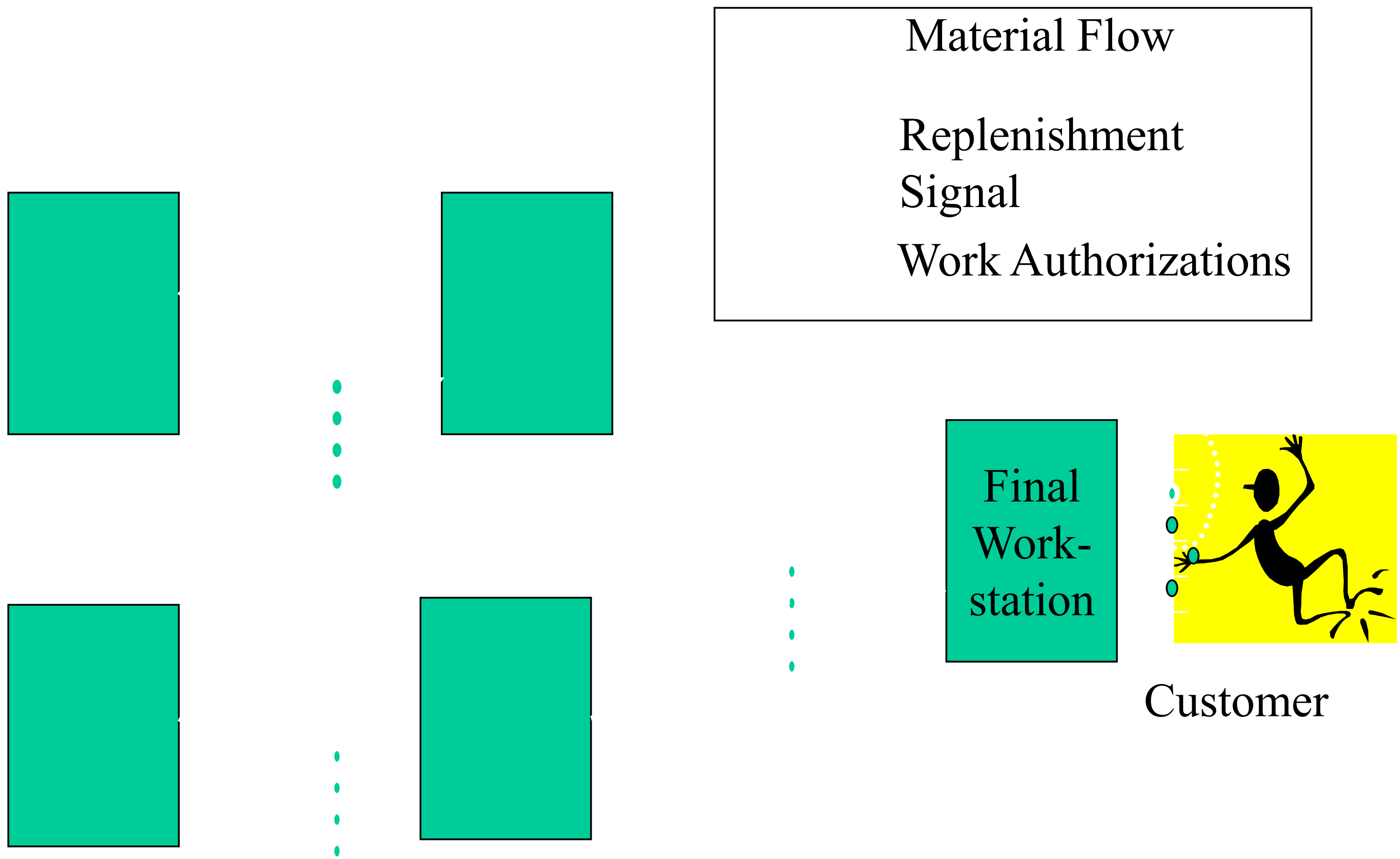
Make All We Can Just In Case We Need It!

Pull System

- Small Lots
- Visual Shop Floor Management
- Minimal Waste
- Good Communication
- Actual/Real Time Information

Make What the Customer Needs When Needed In the Quantity Needed!

Pull System Function



Perfection

Continuously Pursue Perfection;

- Create a clear vision.
  - Production ideal state.
  - Customer Value
- Make waste visible & evident.
- Problem Solving

Buzzing Lean Terminology

- Continuous Flow
- Just-in-Time
- MUDA
- Action Workout
- Pull Production
- Lead Time
- Visual Management
- Value Stream

Buzzing Lean Terminology

Continuous Flow

Just-in-Time

MUDA

Action Workout

Pull Production

Lead Time

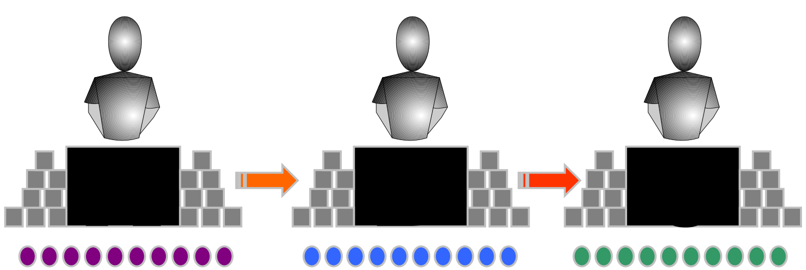
Visual Management

Value Stream

Continuous Flow

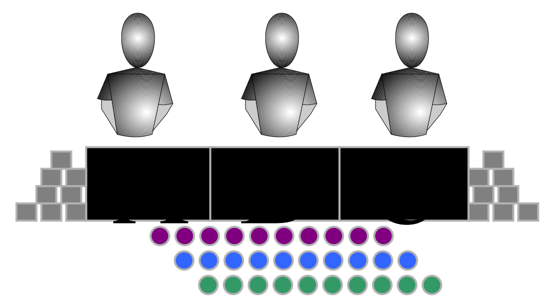
- One of the five principles of Lean
- Involves continuous movement of products, services, or information from end-to-end in a process
- Minimizes batch processing

Batch Processing – 1 minute per piece



Cycle Time = 30++ Min

Continuous Flow – Make One Dispatch One



Cycle Time = 12 Min

Buzzing Lean Terminology

- Continuous Flow
- Just-in-Time
- MUDA
- Action Workout
- Pull Production
- Lead Time
- Visual Management
- Value Stream

Just-in-Time (JIT)

- Philosophy of providing the right part, item, or information in the right place, in the right amount, and at the right time
- Against the mass production principle
- Reduces all cost associated with inventory

Low inventory costs

Against mass production

All about Waste (3M) - Identifying it and Removing it

MUDA = Waste of using resources without creating added value
MURI = Waste of overburdening people or equipment/resources
MURA = Waste of unevenness, variability in processes

Buzzing Lean Terminology

Continuous Flow

Just-in-Time

MUDA

Action Workout

Pull Production

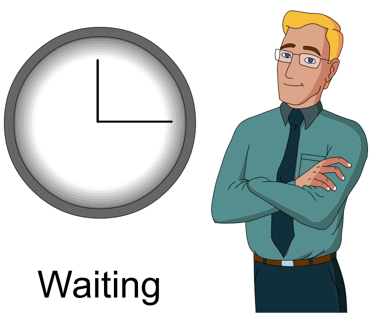
Lead Time

Visual Management

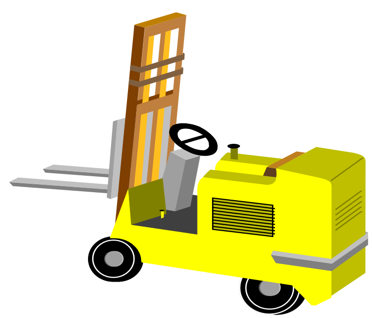
Value Stream

MUDA

- Any type of waste element that adds no value to the product
- Increases cost and lead in time
- Eight types of wastes are: motion, waiting, overproduction, processing, defects, inventory, and transportation.



Waiting



Transportatio
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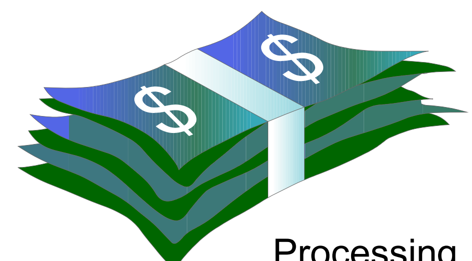
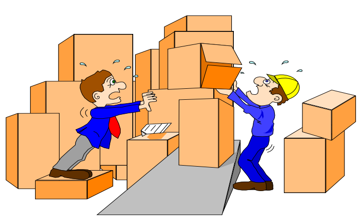
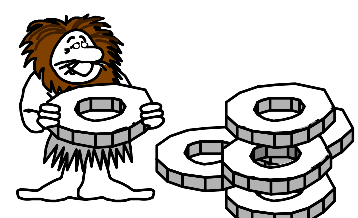


Processing Cost

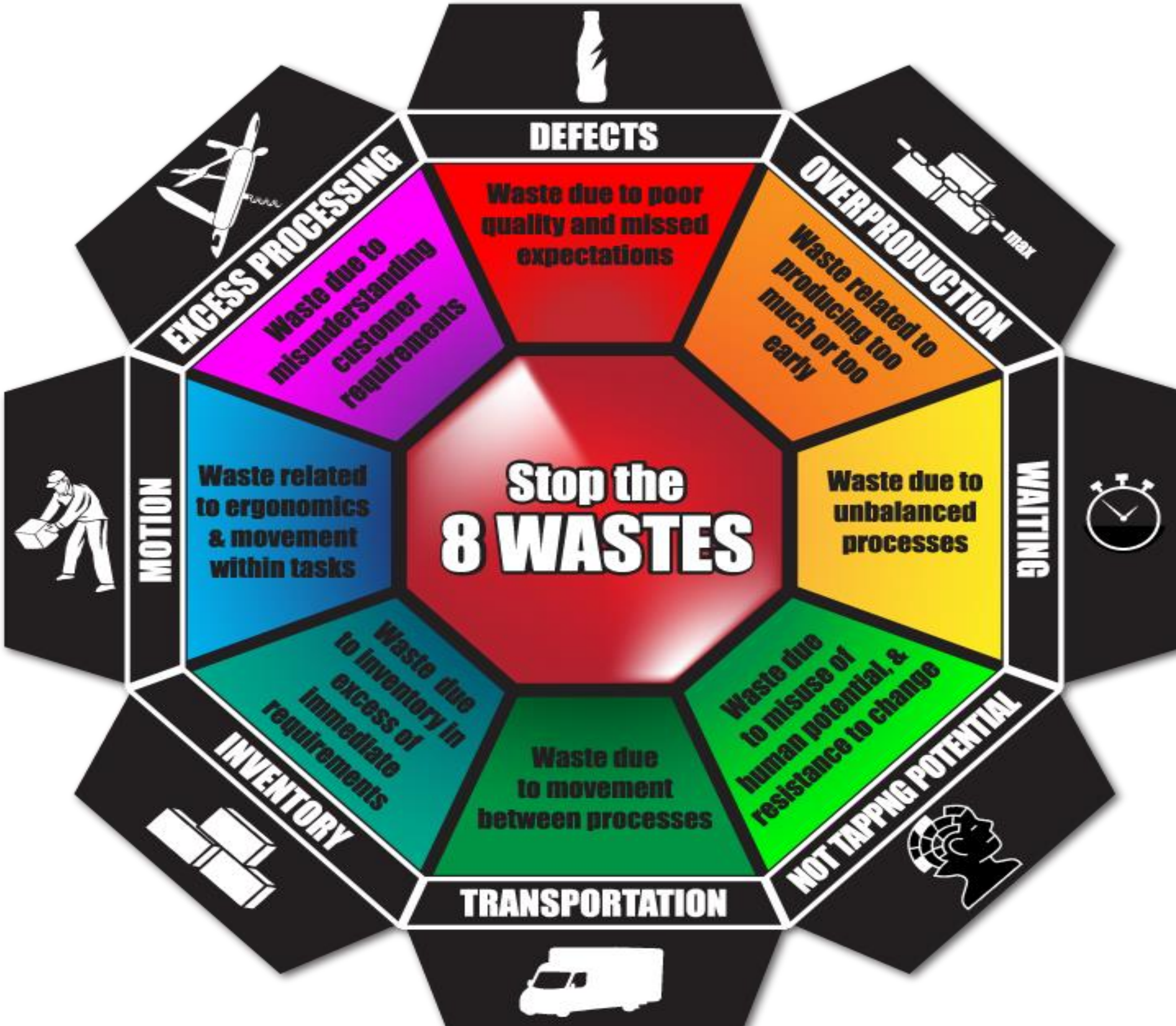


Inventory



Overproduction

The 8 Wastes


Stop the 8 WASTES
DEFECTS
Waste due to poor quality and missed expectations
OVERPRODUCTION
Waste related to producing too much or too early
max
WAITING
Waste due to unbalanced processes
NOT TAPPNG POTENTIAL
Waste due to misuse of human potential, & resistance to change
TRANSPORTATION
Waste due to movement between processes
INVENTORY
Waste due to inventory in excess of immediate requirements
MOTION
Waste related to ergonomics & movement within tasks
EXCESS PROCESSING
Waste due to misunderstanding customer requirements

DOWNTIME (The 8 Wastes, explained)

Defects	• Waste related to poor quality (Supply Chain) • Waste related to mistakes and missed expectations (Back-office, Support functions)
Overproduction	• Producing more product than needed for immediate consumption or customer requirements (Supply Chain) • Performing tasks earlier than needed, pulling resources from higher priorities (Back-office, Support functions)
Waiting	• Product, people, or machines delayed due to earlier processes (Supply Chain) • System elements which cannot perform tasks, due to upstream considerations (Back-office, Support functions)
Not Tapping Potential	• Waste due to not fully utilizing resources available (including human intellect) • Waste related to resisting new ways of thinking or performing functions
Transportation	• Waste related to physical movement of product to different locations (Supply Chain) • Waste related to moving physical or virtual elements across locations (Back-office, Support functions)
Inventory	• Waste related to storing product without specific, current requirements (Supply Chain) • Collecting physical or virtual elements, without actual/immediate need (Back-office, Support functions)
Motion	• Waste related to movement of people or equipment within a task • Waste related to poor ergonomics, or movement within the „envelope" of the body
Excess Processing	• Waste related to not understanding actual customer requirements • Performing tasks & functions with greater depth than actually required for the purpose at hand

Waste #1: Defects

This is the waste related to <u>poor quality</u>, such as:

- Input errors
- Creating defects
- Routing defects
- Finding defects
- Correcting defects
- Recording defects
- Repo

Examples :

- Incorrect data entry
- AR collection not as per the timeline
- Invoice error
- Improper account code
- Invoices not matching with PO
- Credit Terms & Default clauses not properly negotiated with the customer

Waste #2: Over-Production

This is waste related to producing ahead of customer requirements, such as:

- Over-ordering
- Early scheduling
- Producing more product than is required for immedi[illegible] or shipping

Examples :

- Processing paperwork before the next person is ready for it.
- Producing 60 invoices in a day when client wants only 40 invoices processing in a day

Waste #3: Waiting

This is waste related to <u>system imbalances & flow related issues</u>, such as:

- People waiting for processes to finish
- Processes waiting for the previous process to complete
- Product waiting for the rest of the batch to be completed
- Anything which should be „flowing‟but is standing still

Examples :

- **Invoices waiting in queue before being processed**
- **Redundant approvals**
- **Unbalanced workload**
- **Waiting „on-hold‟on the phone for getting clarification from units on invoices discrepancy**
- **Waiting for a signature to proceed with an order**

Waste #4: Not Tapping Potential

Waste due to <u>not fully utilizing resources</u>:

- Not utilizing human potential
- Not soliciting and using the ideas of others
- Not engaging people in the change process
- General resistance to change

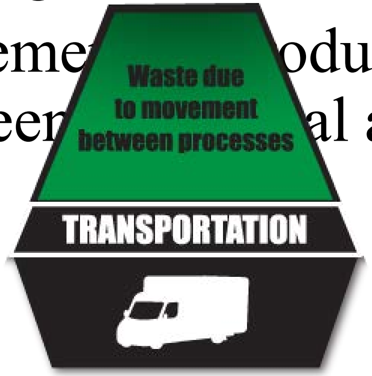
Examples in

- Not leveraging the qualities of individual to the fullest.
- Keeping improvement ideas to yourself
- Not participating in team discussions
- Not inviting outside eyes to evaluate local processes
- Squashing the ideas of younger teammates

Waste #5: Transportation

This is waste related to <u>movement of people, product, and machines</u>, such as:

- People and product moving between workstations
- People and product moving within work areas
- Moveme oduct between al areas



Examples :

- Multiple approvals
- Files moving from one desk to another
- An invoice with error being taken for further processing

Waste #6: Inventory

This is waste related to materials and product in excess of current customer requirements, such as:

- Raw materials
- WIP (work-in-process)
- Finished goods

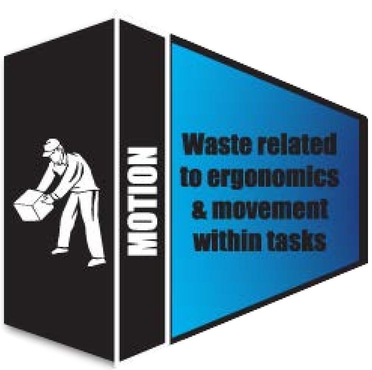
Examples

- More stationary than required
- Documents/ records hold beyond retention period.
- Batch processing of invoices
- Processed invoices not delivered to customer

Waste #7: Motion

This is waste related to people and machine movement within a task, such as:

- Hand and arm motion
- Machine stroke/cycle
- Control movement on equipment



Examples

- Searching for information for matching the PO detail from invoice
- Collection agency going to wrong address
- Scattered departments in an organization

Waste #8: Excess Processing

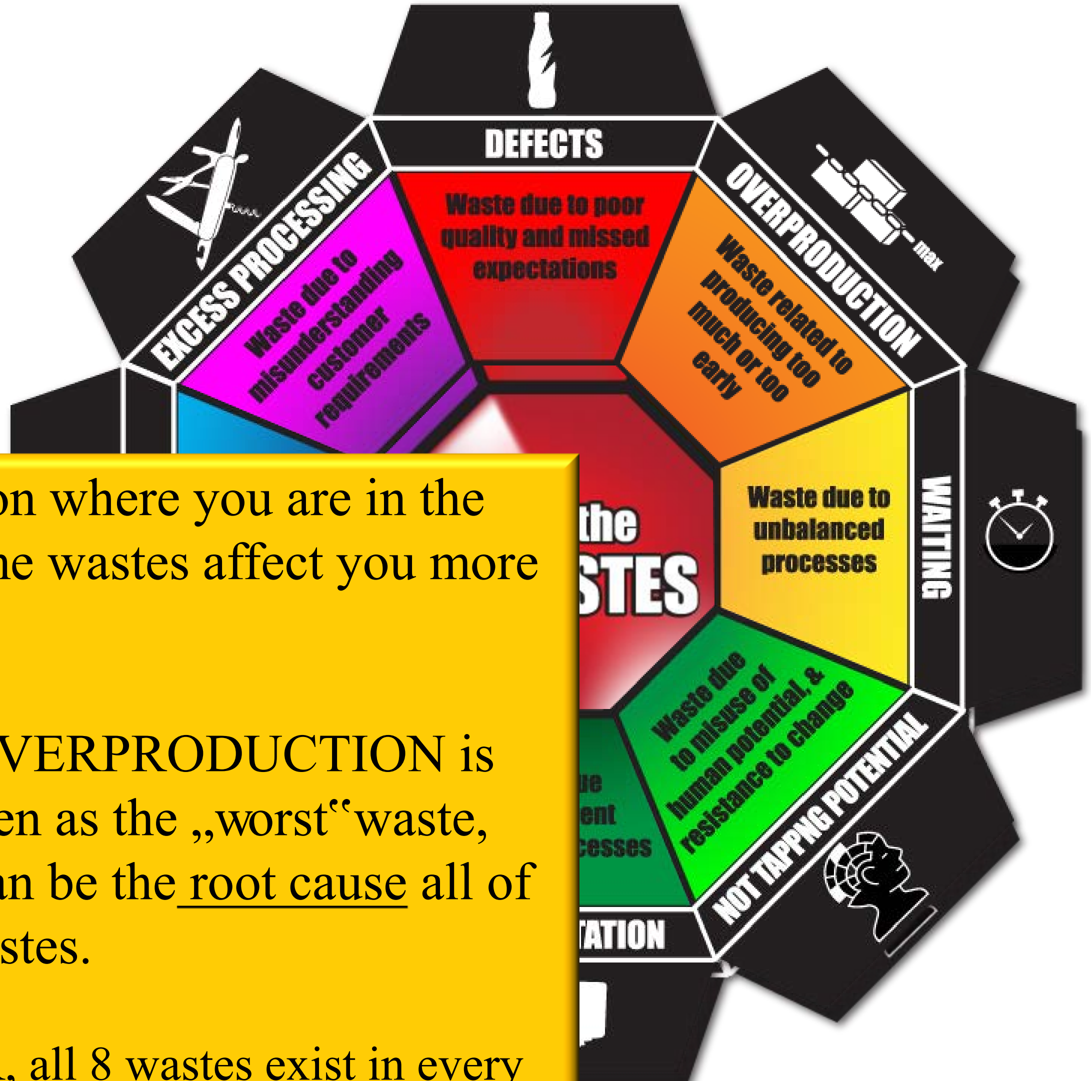
This is waste related to misunderstanding customer requirements, such as:

- Cleaning in excess of requirements (and re-cleaning)
- Inspections
- Moving product, then moving again
- Generating trash
- Other non-value-added steps

Examples :

- Surplus/redundant steps in a process
- Excessive no of meetings
- Requiring various signature levels for minor purchases
- Endless refinements/ approvals before sending presentation to your boss / customer

Which is the 'worst' waste?



Depending on where you are in the process, some wastes affect you more than others.

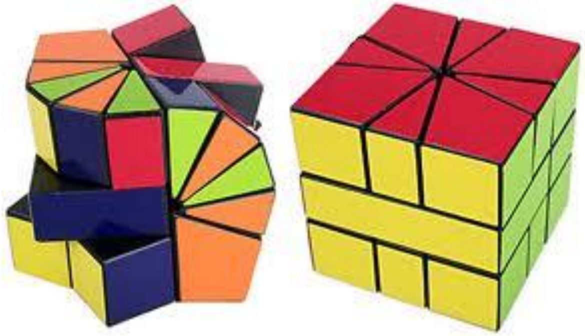
However, OVERPRODUCTION is generally seen as the „worst"waste, because it can be the <u>root cause</u> all of the other wastes.

REMEMBER, <u>all</u> 8 wastes exist in every process, to one degree or another!

MURA

Mura means IRREGULARITY

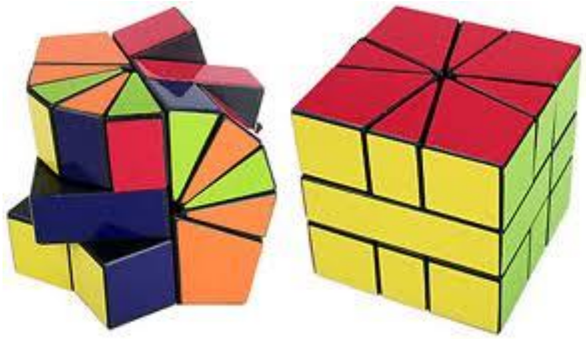
Whenever a smooth flow of work is interrupted in an operator's work, the flow of parts and machines, or the production schedule, there is ***mura***



MURA

Mura means IRREGULARITY

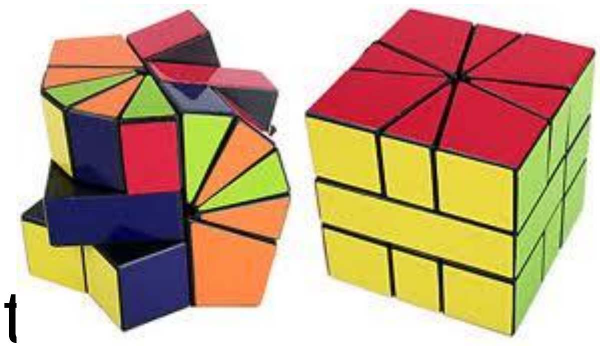
It can occur in:



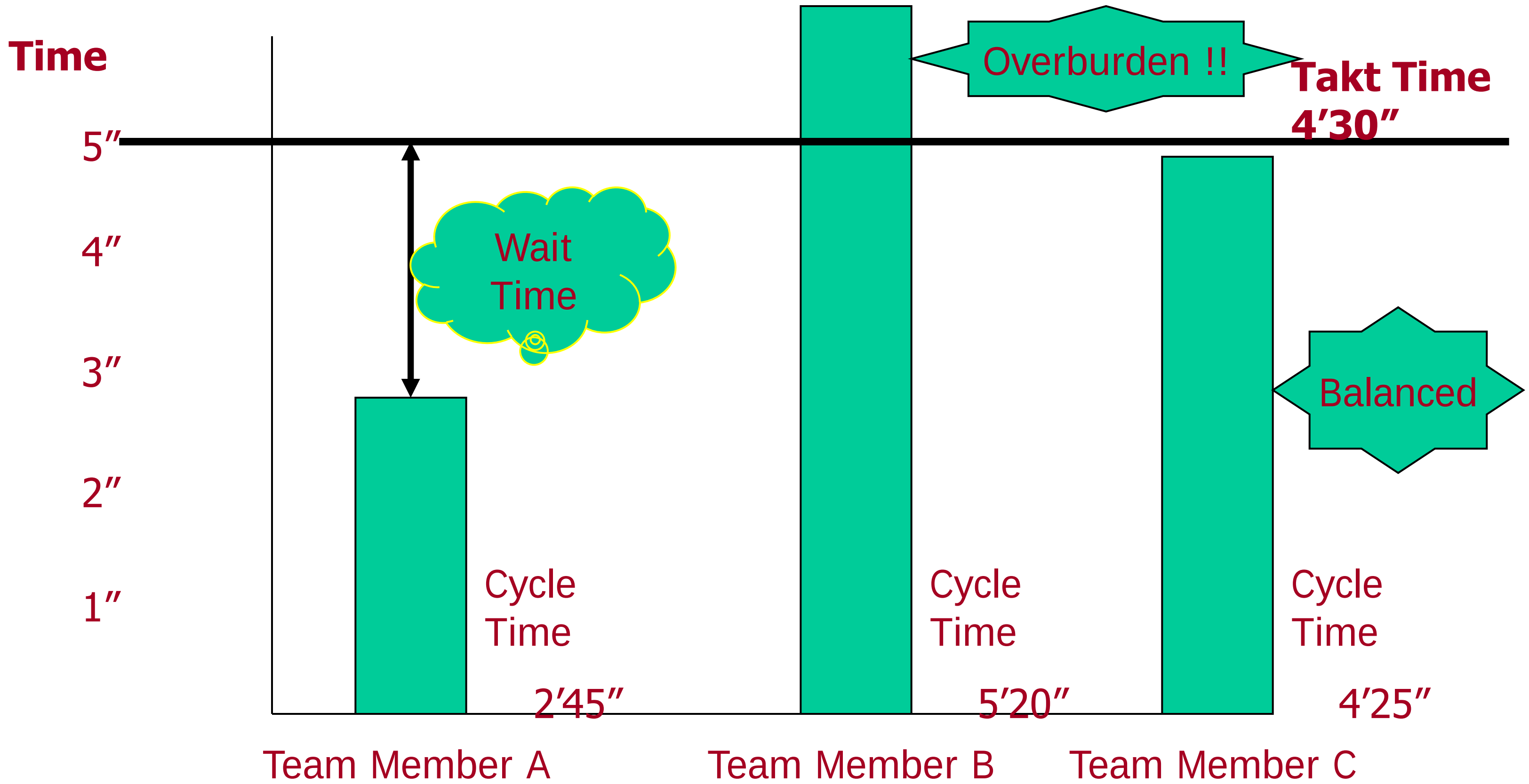
- Production
- Parts flow
- Equipment usage
- Work done by team members
- Information flow
- Material deliveries, causing shortage or overstock

MURA

- Benefits of eliminating Mura:
  - Shorter Lead times
  - Lower WIP
  - Faster response time
  - Lower cost
  - Greater production flexibility
  - Higher quality
  - Better customer service
  - Higher revenue
  - Higher throughput
  - Increased profit !

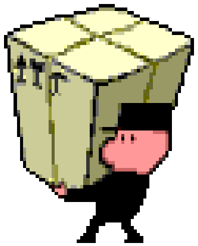


MURA



Time
5″
4″
3″
2″
1″
Takt Time
4′30″
Overburden !!
Wait
Time
Balanced
Cycle
Time
2′45″
Cycle
Time
5′20″
Cycle
Time
4′25″
Team Member A
Team Member B
Team Member C

MURI



Muri means strenuous conditions for both workers and machines as well as for the work process.

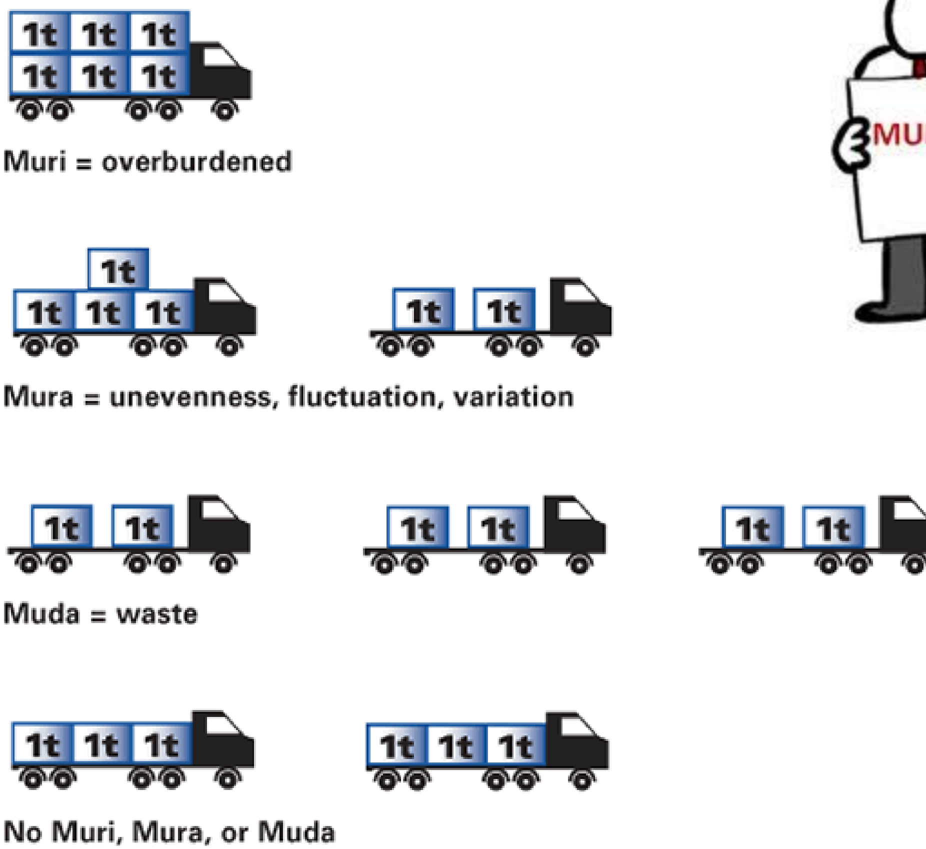
- When machines are overburdened
  - We run the risk of causing safety hazards, equipment breakdowns and manufacturing defects.
- When team members are overburdened:
  - The safety of the team members can be endangered
  - Workers are more likely to become exhausted or fatigued
  - It becomes difficult for team members to do each job with attention to detail. This increases the frequency of defects, which in turn adversely affects the quality.

MURI

Muri means STRENUOUS WORK

- A profusely sweating operator
- Squeaking sound from the machine
- A newly hired worker assigned to do the job of a veteran without adequate training

MUDA MURA MURI



Buzzing Lean Terminology

- Continuous Flow
- Just-in-Time
- MUDA
- Action Workout
- Pull Production
- Lead Time
- Visual Management
- Value Stream
- Takt Time

Action Workout (Kaizen)

- Team-based activity focused on quickly solving problems through physical simulation and evaluation
- Also referred to as Kaizen
- Means by which workers are able to communicate their ideas and create change

Kaizen

Kai + zen

(Change for the better)

Kaizen Kaizen Event

The definition of “Kaizen” has been Americanized to mean "Continual Improvement." A closer definition of the Japanese meaning of Kaizen is "to take apart and put back together in a better way."

Real Sense

- Everyday Improvement
- Everybody Improvement
- Everywhere Improvement

~~ISOLATI~~
~~ON~~

~~SECRECY~~

“Do you have
any ideas ?”

“Here‟s what
we are doing

“What problems
Can we solve ?”

“Here‟s where
We are going

“How can we make
this better ?”

COMMUNICATION

Kaizen Event

- Identify a problem
- Brainstorm with employees
- Make the improvement
- Monitor results
- Adjust as necessary
- Apply to like processes

Must requirements for Running Kaizen

- One Kaizen Facilitator from Quality Team
- Drive from Leadership for kaizen
- Reward & recognition

Kaizen Closure report

Problem Statement:-

Leader:

Members:

Project ID:

Location

Start Date

End date

Bench Mark

Target

Analysis

Why 1	Why 2	Why 3

Root cause:

Counter Measure

Benefits:

Improvement Trend:

Horizontal Deployment

Kaizen reward and Recognition

(Every 6 months)

1. Top 3 winners from furniture plant
2. One award for maximum no. of projects nominated from each department
3. One award for maximum no. of projects nominated from single individual
4. Consolation prize to all the participants
5. Certificate of participants for all

Project recognition criteria

Jury Members :- Manager from particular department& Quality Head

Evaluation Criteria

Sl No.	Criteria	Score
1	Process Improvement	10
2	Cost Saving	15
3	Process parameter improvement	15
4	Customer satisfaction	10
5	Employee satisfaction	05
6	Innovation	10
7	Sustaining Period	10
8	Quantum Change(average & variation)	10
9	Replication possibility	05
10	Standardization(automation,process & review)	10

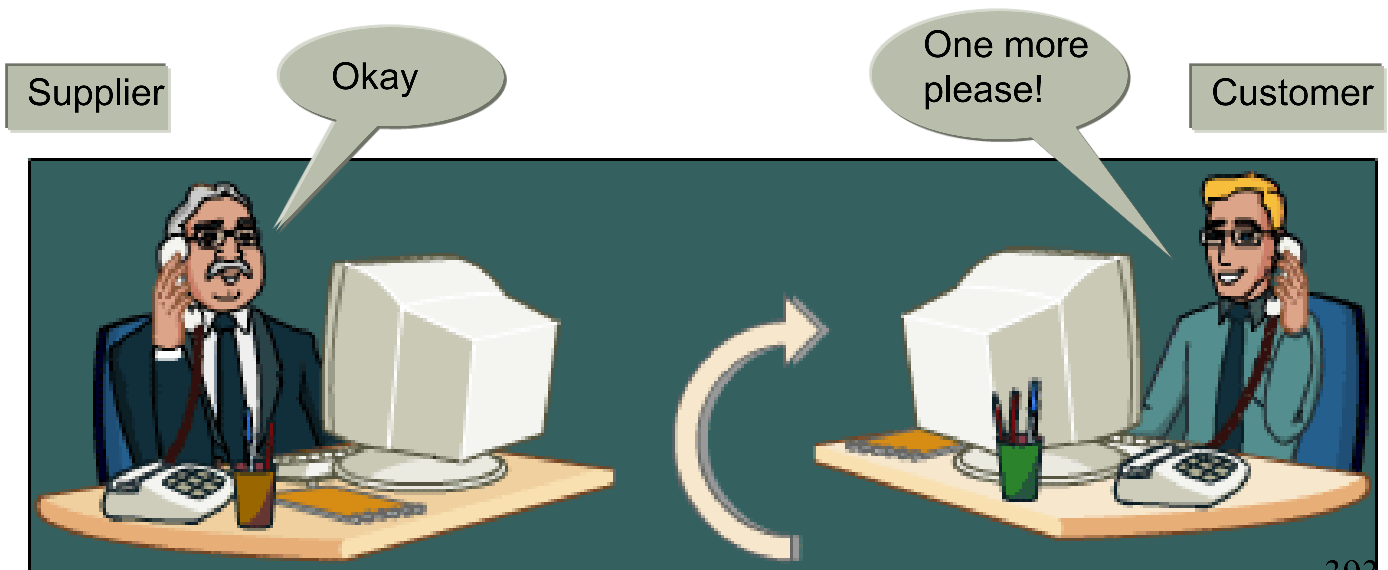
Total Marks for each project is 100

Buzzing Lean Terminology

- Continuous Flow
- Just-in-Time
- MUDA
- Action Workout
- Pull Production
- Lead Time
- Visual Management
- Value Stream

Pull Production

- Customer-centric activity where production is based upon the client requirements
- Reduces waste by minimizing overproduction
- Uses demand-related signals from clients



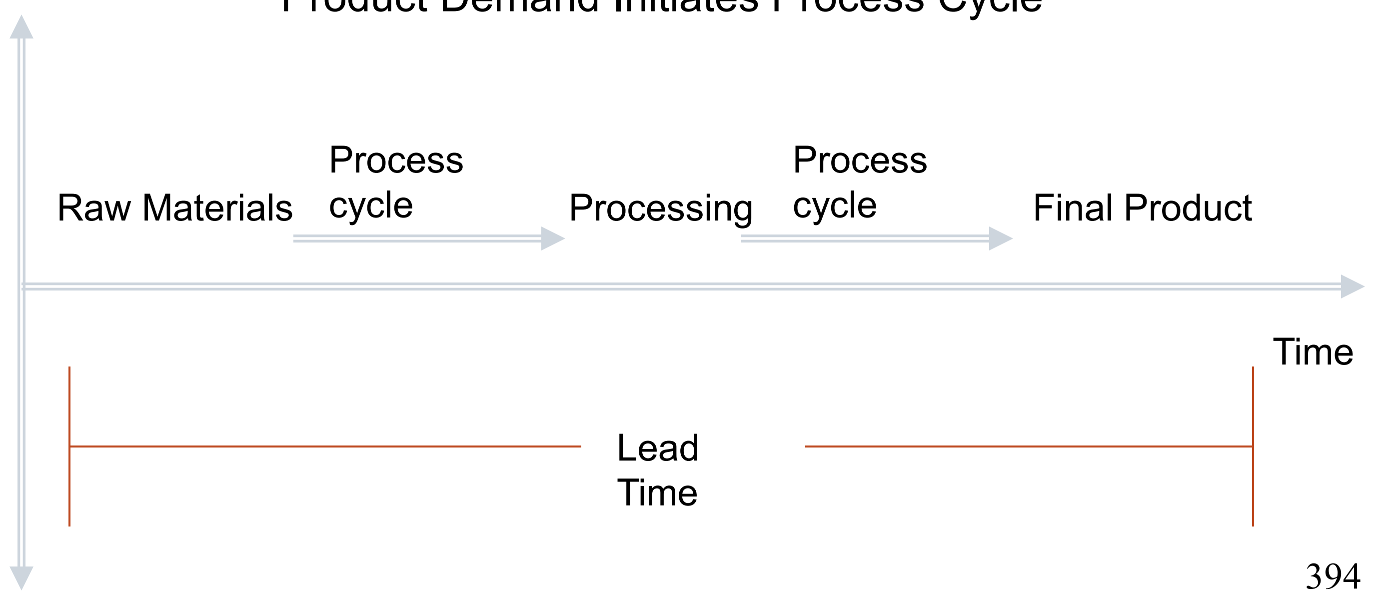
Buzzing Lean Terminology

- **Continuous Flow**
- **Just-in-Time**
- **MUDA**
- **Action Workout**
- **Pull Production**
- **Lead Time**
- **Visual Management**
- **Value Stream**

Lead Time

- Refers to the total time from when an order is placed until the finished product is shipped.
- Decreased lead time results in JIT-favoring production environment

Product Demand Initiates Process Cycle



Buzzing Lean Terminology

Continuous Flow

Just-in-Time

MUDA

Action Workout

Pull Production

Lead Time

Visual Management

Value Stream

Visual Management

- Means by which anyone can tell at a glance if the production activities ar proceeding normally or not
- A communication, discipline, and pacing tool

Organize and arrange what you need!!

- Visual Management
  - a system of visual signals (indicators & controls) that convey information about system status and desired behaviors in the workplace

- A VISUAL INDICATOR relates information and data to employees in the area.

For example: charts showing the daily production of a line, or Chart depicting where cleaning activity is to be done etc

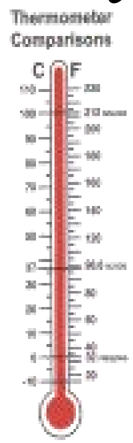
- A VISUAL CONTROL is intended to actually control or guide the action of the group members.

For example: Danger signs, Warning charts, Shadow boards etc

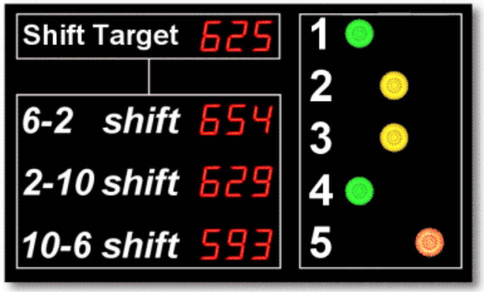
Exampl

- Visual indicators convey system status:

Andon lights show line status



Thermometers indicate temperature



Display boards convey metrics

This light shows when recording is taking place

Popup thermometers indicate when the turkey is done

These lights indicate sound level

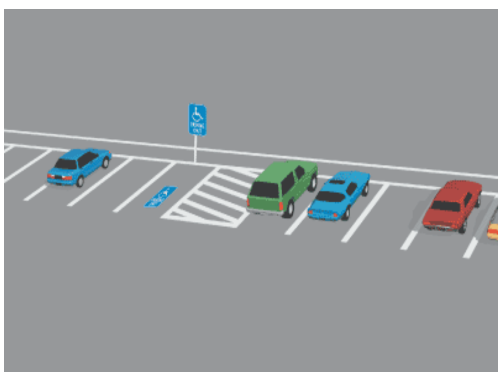
Exampl

- Visual controls indicate desired behaviors:

Stop signs control traffic flow


Shadow boards control tool position (and <u>indicate</u> missing tools as well)


Stop lights control traffic flow


Parking spaces control auto storage locations

Signage controls actions


These lines control traffic & travel

5 S and Visual Management

WHAT PROBLEMS DO U COMMONLY ENCOUNTER AT YOUR WORKPLACE

- HIGH ABSENTEEISM
- HIGH TURNOVER
- DEMOTIVATED EMPLOYEES
- DISORDERED/ CLUTTERED ENVIRONMENT
- MISTAKES/ERRORS

THE SOLUTION TO ALL THESE PROBLEMS IS

5S

Workplace Maintenance

What is important to construct a strong building ?

Strong

&

Good Foundation

is the basic criteria to construct

a rigid structure!

Workplace Maintenance

Is the foundation

What is 5S ?

- 5S is a simple but highly effective set of techniques
- 5S methodology was developed in Japan
- 5S is the foundation for any continuous improvement
- 5S removes waste from work environment through better workplace organization, standardization, visual communication and general cleanliness

A necessary pre-condition for improvement culture

What are the 5Ss ?

5Ss	Japanese	English	Meaning
1 S	SEIRI	SORT	Remove unwanted items from the work place
2 S	SEITON	SET	A place for everything and everything in its place
3 S	SEISO	SHINE	Cleaning with meaning
4 S	SEIKETSU	STANDARDISE	Establish Standards for first 3Ss
5 S	SHITSUKE	SUSTAIN	Sustain & improve the first 4Ss

1. ORGANISATION(SEIRI)

- Decide what you need
- Remove unnecessary clutter
- All tools, gauges, materials, classified and then stored
- Remove items which are broken, unusable or only occasionally used

RED TAG TECHNIQUE

RED
TAG

- GIVE STAFF RED LABELS
- ASK STAFF TO GO THROUGH EVERY ITEM IN THE WORK PLACE
- ASK IF NEEDED & THOSE THAT ARE NEEDED, IN WHAT QUANTITY
- NOT NEEDED RED TAG IT
- STORE IN THE RED TAG AREA

RED
TAG

For wavering items

- PLACE THE SUSPECTED ITEMS IN THE RED TAG AREA FOR ONE WEEK
- ALLOW THE STAFF TO REEVALUATE THE NEEDED ITEMS
- AT THE END OF WEEK THOSE WHO NEED ITEMS SHOULD BE RETURNED

ORGANISATION

PRIORITY	FREQUENCY OF USE	HOW TO USE
Low	Less than once per year Once per year	Throw away Store away from the workplace
Avg.	Once per month Once per week	Store together but offline
High	Once Per Day	Locate at the workplace

ORDERLINESS(SEITON)

- ONCE YOU HAVE ELIMINATED ALL THE UNNEEDED ITEMS

- NOW TURN TO THE LEFT OVER ITEMS

ORDERLINESS(SEITON)

Organise layout of tools and equipment

- Designated locations
- Use tapes and labels
- Ensure everything is available as it is needed and at the “point of use”

Examples Of Types Of Waste Avoided By Set In Order-Advantages

- The Waste of Motion
- The Waste of Searching
- The Waste Of Human Energy
- The Waste of excess inventory
- The Waste of defective locations
- The Waste of unsafe conditions

Cleaning/inspection Check list

No.	Point	Main response			
		Clean	Lubricate	Replace	Restore
1	Is there any dirt or dust in the oil inlet?	O			
2	Do the oil level indicators show adequate levels?		O		
3	Can the oil level indicators be clearly seen?	O			
4	Are there crack in the oil tank?				O
5	Is the oil tank bottom dirty?	O			
6	Is the oil in the tank dirty?			O	
7	Is there any oil leakge from the tank?			O	O
8	Are oil levels adequate?		O		
9	Is the correct type of oil being used?			O	

4S : Standardize Practices

- Color coding (Tools, jigs, fixtures….)
- Poke-yoke
- Responsibility labels
- Wire management (PCs, LCDs)
- Inspection marks
- Prevention of dust, dirt, noise and vibration
- I-can-do-it-blindfolded
- Visual control signs

5S Leads to

House Keeping	→	Orderliness
Orderliness	→	Cleanliness
Cleanliness	*LEADS TO*	Quality
Quality	→	Productivity
Productivity	→	Success
Success	→	Happiness

BEFORE-AFTER

- Before

- After

BEFORE-AFTER

5S Leads to

House Keeping	→	Orderliness
Orderliness	→	Cleanliness
Cleanliness	*LEADS TO*	Quality
Quality	→	Productivity
Productivity	→	Success
Success	→	Happiness

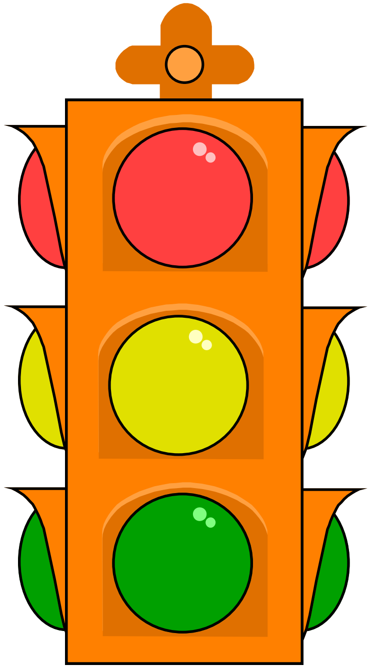
Overview of "KANBAN"

What is Kanban?

In Japanese language, the word

- **“Kan” means “Card" and**
- **"ban" means “Signal".**

So “Kanban” refers to as “Signal Cards".



KanBan

- KanBan is a pull-material replenishment system, based on the principle that material is pulled through the production process based on actual usage.
- Kanban uses visual signals, usually a card (KanBan card), to move material through the value chain.

KanBans / Signals

There are two types of Kanban cards:

- a conveyance card (C-Kanban)
- a production card (P-Kanban)

Signals come in many forms other than cards, including:

- an empty crate
- an empty designated location on the floor

How Kanban works : A simple example

Let's assume you are manufacturer of **Head Lamp.**

- **Components required : Lens**
- **Packaging : Pallets**
- **No. of lenses per pallet : 50**

- When the pallet is empty, the person assembling the Head Lamps takes a "Card" that was attached to the pallet and sends it to the "Lens" manufacturing area. Another pallet of "Lens" is then manufactured and sent to the Head Lamp assembler.
  - A new pallet of "Lenses" is not made until a "Signal Card" is received.
- This is **"Kanban"**, in it's simplest form.

Kanban Control System

- Card or other device that communicates demand for work or materials from the preceding station
- A method of Just-in-Time inventory replenishment that originated in Japan.
- Paperless production control system
- Authority to pull, or produce comes from a downstream process.

Kanban techniques can be used by both manufacturing” and “non-manufacturing” org’s

KANBAN Card

Address	**Location**
Supplier Name AMTAX	**KANBAN #** W22X
Supplier Code 0500	
Shipping Frequency 5 Times/Week	**Safety Stock** 9 / **Days** 1

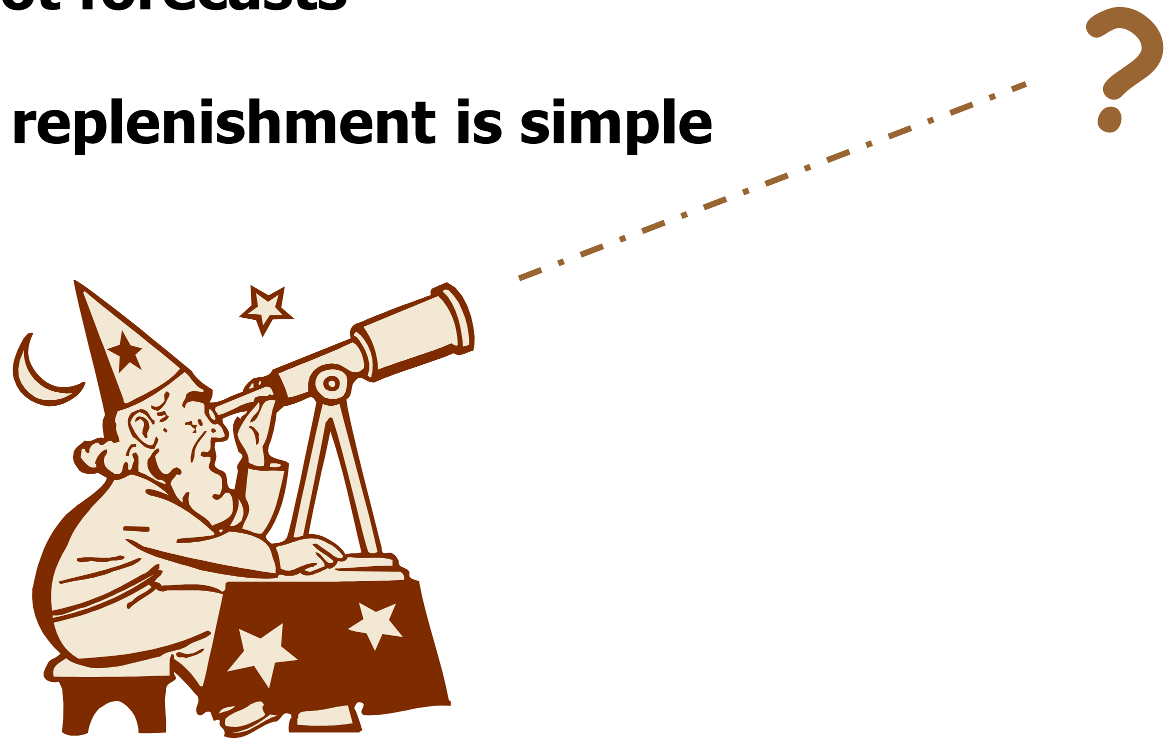
Why Consider Kanban Control?

- **Lower inventory investment**
- **Better "customer" service**
- **Reduced administrative costs**

What makes Kanban Control different ?

- **Kanban is “pull” based – driven by actual usage not forecasts**

- **Kanban replenishment is simple**



Kanban System

Can use different methods to trigger replenishment activity

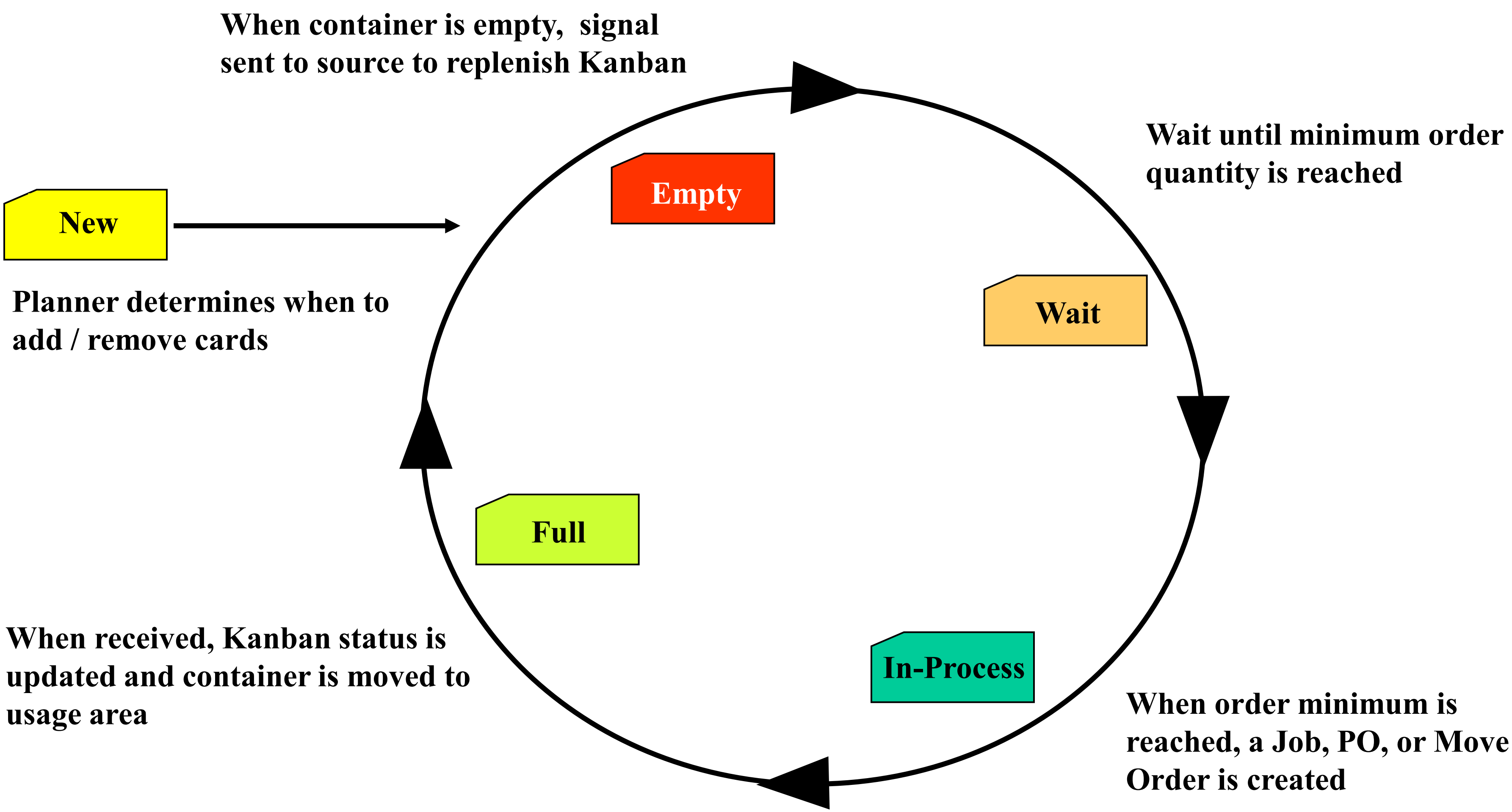
- **Kanban cards are the most common**
- **Kanban containers are frequently**
- **bar coding of cards / containers helps when automating Kanban systems**

Kanban System

Not suited for all inventory items – look for

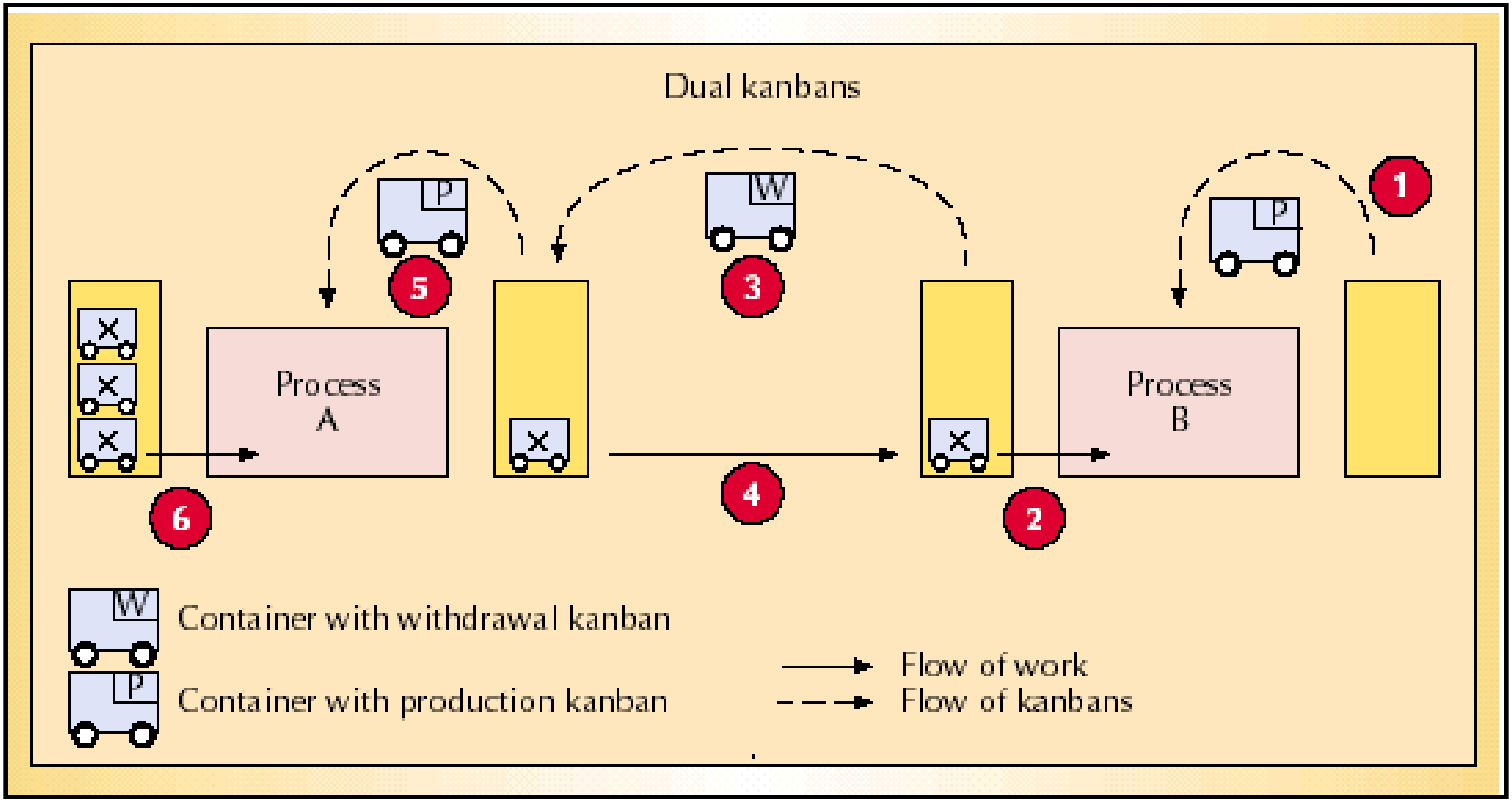
- **items with frequent usage**
- **items with short lead times**
- **items with “willing” suppliers**

Replenishment Flow for Kanban Cards



Types of Kanban

- **Production Kanban**
  - **authorizes production of goods**
- **Withdrawal/Conveyance Kanban**
  - **authorizes movement of goods**
- **Kanban square**
  - **a marked area designated to hold items**
- **Signal Kanban**
  - **a triangular kanban used to signal production at the previous workstation**
- **Material Kanban**
  - **used to order material in advance of a process**
- **Supplier Kanban**
  - **rotates between the factory and suppliers**


Dual kanbans
Process A
Process B
1
2
3
4
5
6
P
W
Container with withdrawal kanban
Container with production kanban
Flow of work
Flow of kanbans

Conveyance Kanban

Conveyance Kanban Card

Part number to produce: **M471-36**	Part description: **Valve Housing**
Lot size needed: **40**	Container type: **RED Crate**
Card number: **2 of 5**	Retrieval storage location: **NW53D**
From work center: **22**	To work center: **35**

Production Kanban

Production Kanban Card

Part number to produce: **M471-36**

Part description: **Valve Housing**

Lot size needed: **40**

Container type: **RED crate**

Card number: **4 of 5**

Completed storage location: **NW53D**

From work center: **22**

To work center: **35**

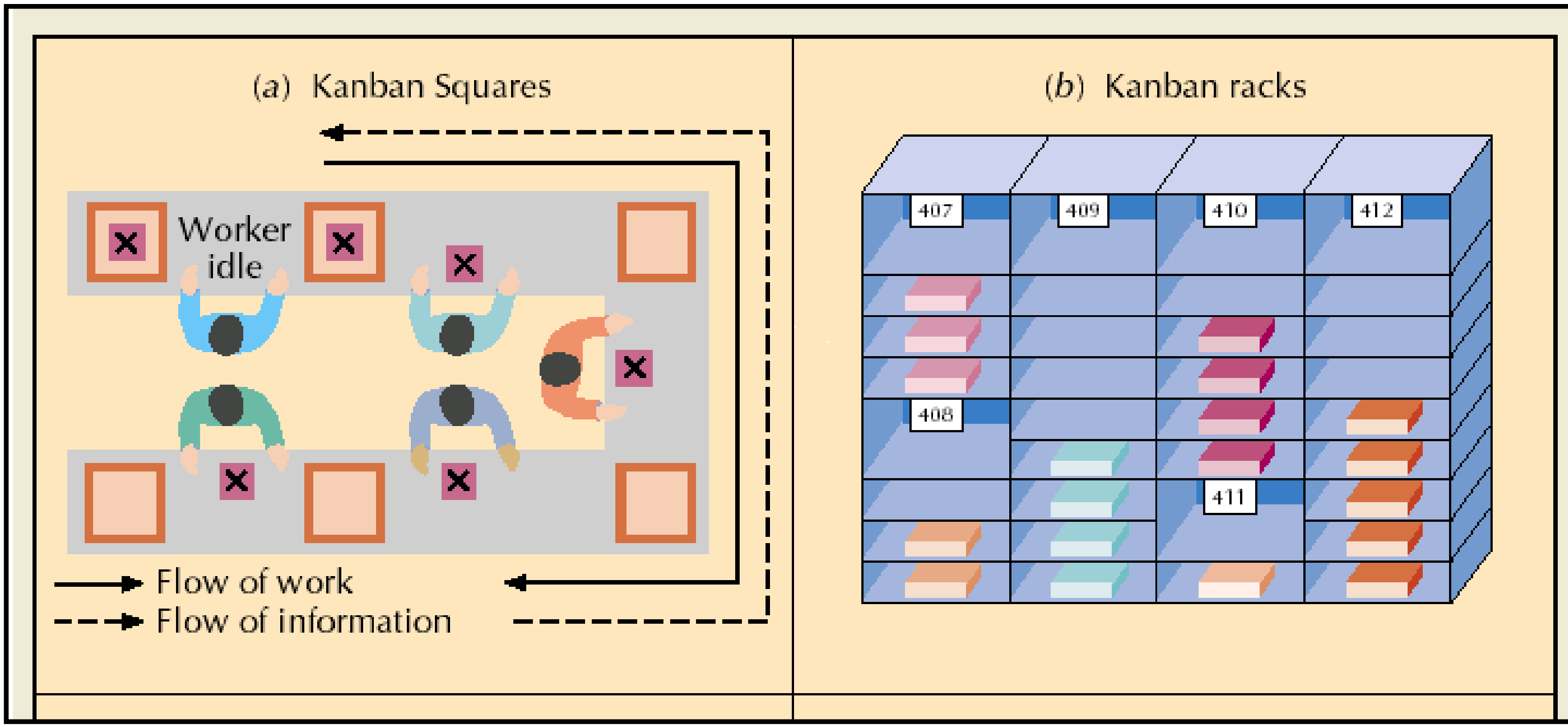
Materials required:

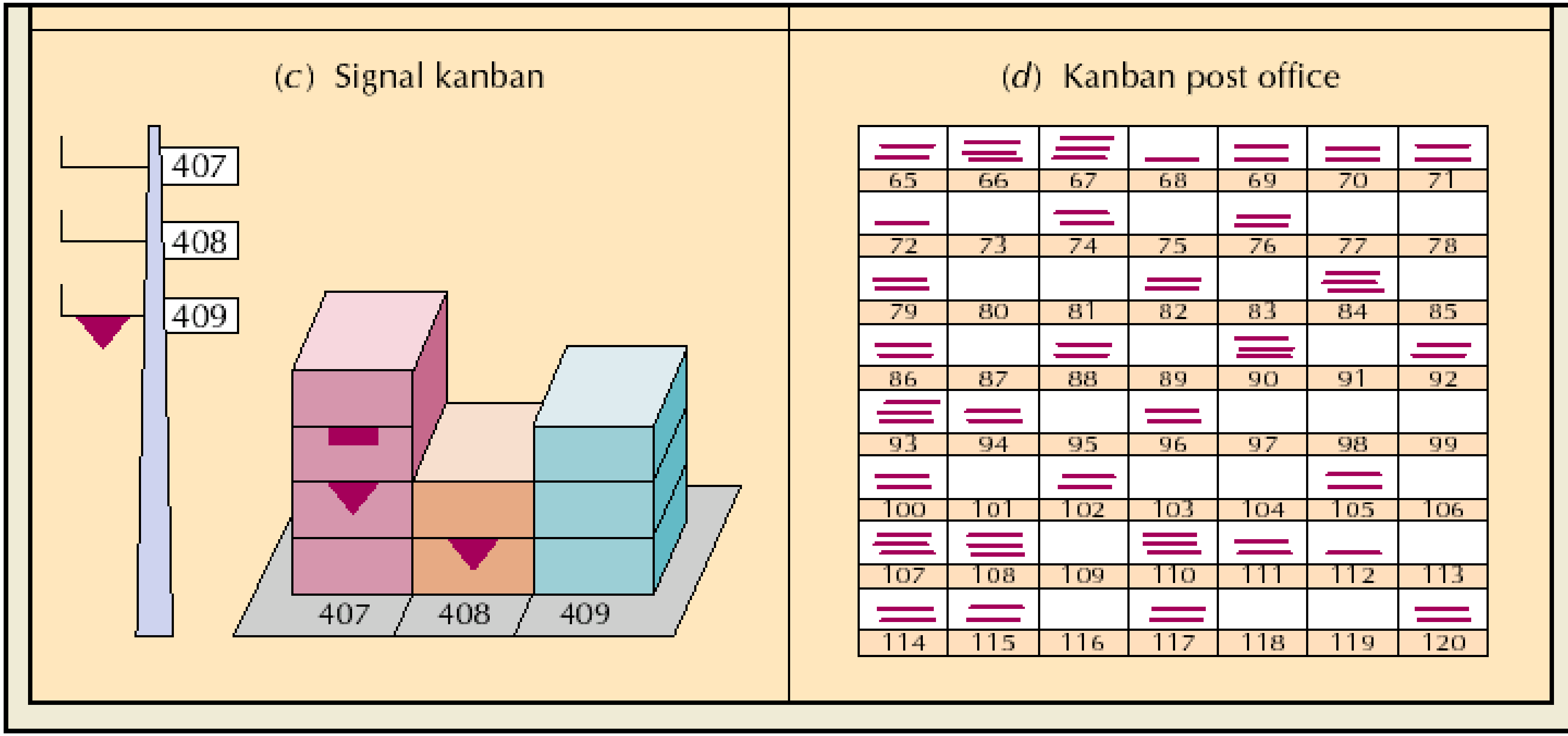
Material no. **744B**	Storage location: **NW48C**
Part no. **B238-5**	Storage location: **NW47B**

How Kanban Operates

When a worker at downstream Work Center #2 needs a container of parts, she does the following:

- She takes the C-Kanban from the container she just emptied.
- She finds a full container of the needed part in storage.
- She places the C-Kanban in the full container and removes the P-Kanban from the full container and places it on a post at Work Center #1.
- She takes the full container of parts with its C-Kanban back to Work Center #2.


(a) Kanban Squares
Worker idle
Flow of work
Flow of information
(b) Kanban racks
407
409
410
412
408
411


(c) Signal kanban
407
408
409
407
408
409
(d) Kanban post office
65 66 67 68 69 70 71
72 73 74 75 76 77 78
79 80 81 82 83 84 85
86 87 88 89 90 91 92
93 94 95 96 97 98 99
100 101 102 103 104 105 106
107 108 109 110 111 112 113
114 115 116 117 118 119 120

Determining Number of Kanbans

$$\text{No. of Kanbans} = \frac{\text{average demand during lead time} + \text{safety stock}}{\text{container size}}$$

$$N = \frac{dL + S}{C}$$

where

N = number of kanbans or containers
d = average demand over some time period
L = lead time to replenish an order
S = safety stock
C = container size

Determining Number of Kanbans: Example

d = 150 bottles per hour
L = 30 minutes = 0.5 hours
S = 0.10(150 x 0.5) = 7.5
C = 25 bottles

$$N = \frac{dL + S}{C} = \frac{(150 \times 0.5) + 7.5}{25}$$

$$= \frac{75 + 7.5}{25} = 3.3 \text{ kanbans or containers}$$

Round up to 4 (to allow some slack) or down to 3 (to force improvement)

Exercise: Number of Containers

There are two adjacent work centers, one of which is fed parts from the other. The production rate of the using work center is 165 parts per hour. Each standard Kanban container holds 24 parts.

It takes an average of 0.6 hour for a container to make the entire cycle from the time it leaves the upstream center until it is returned, filled with parts, and leaves again. The safety stock factor of the system is observed to be 0.2.

How many containers are needed?

JIT - Just In Time / Continual Improvement

- **Kanban** is directly associated with Just-In-Time (JIT) delivery.
  - However, **Kanban** is not another name for just-in-time delivery.
  - It is a part of a larger JIT system.

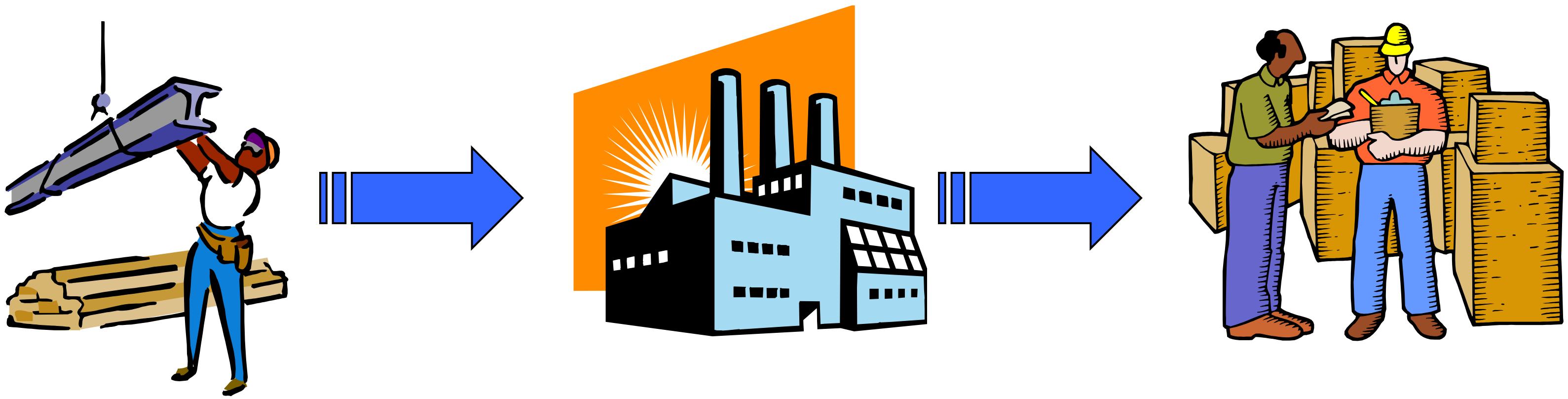
- There is more to managing a JIT system than just Kanban and
  - there is more to **Kanban** than just inventory management.

Value Stream Mapping

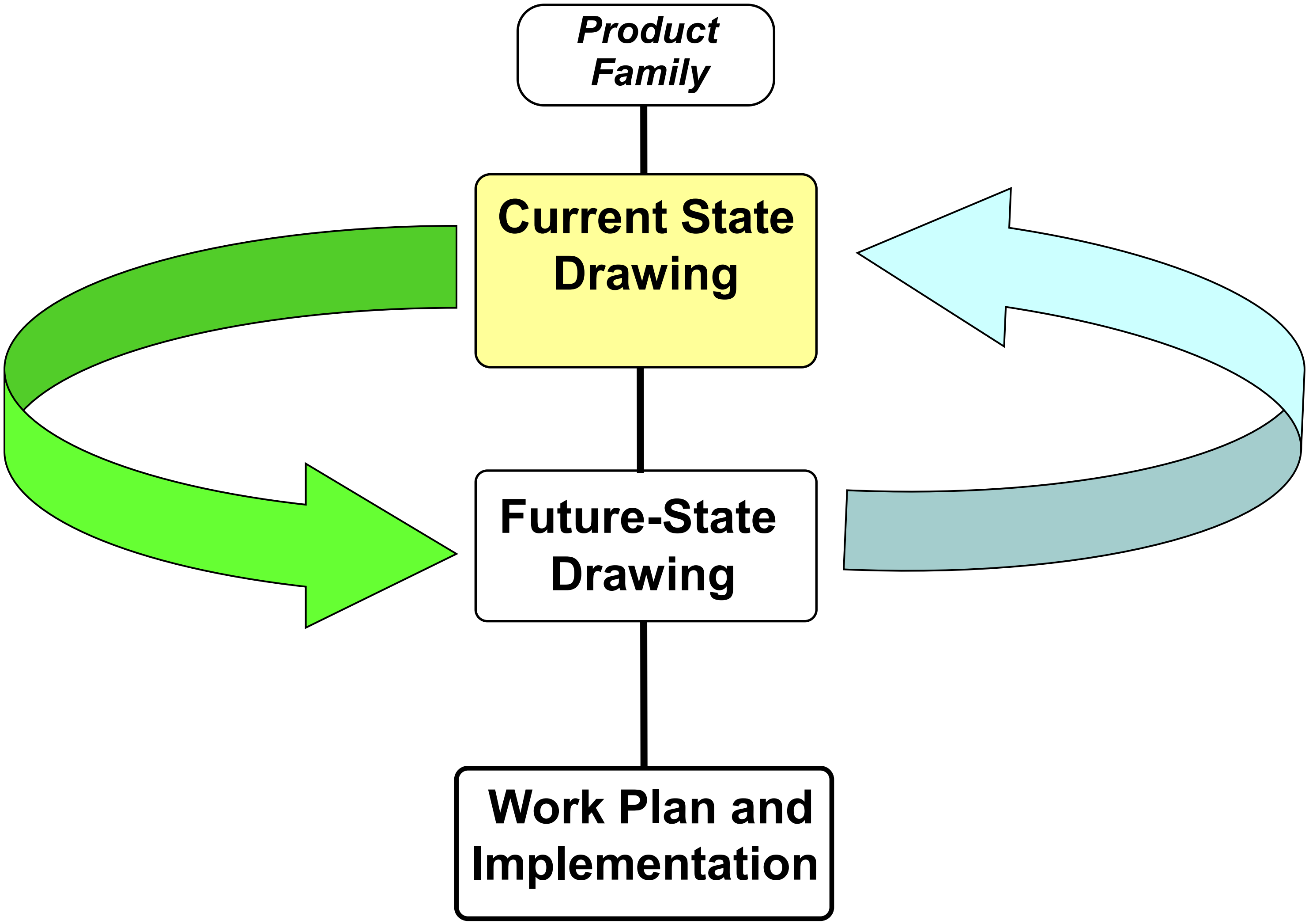
What is Value Stream?

- A value stream is all the actions (Both value added and Non Value added) currently required to bring a transaction though the main flows essential to every transaction

- Taking a value stream perspective means working on the big picture , not individual processes, and improving the whole, not just optimizing the parts

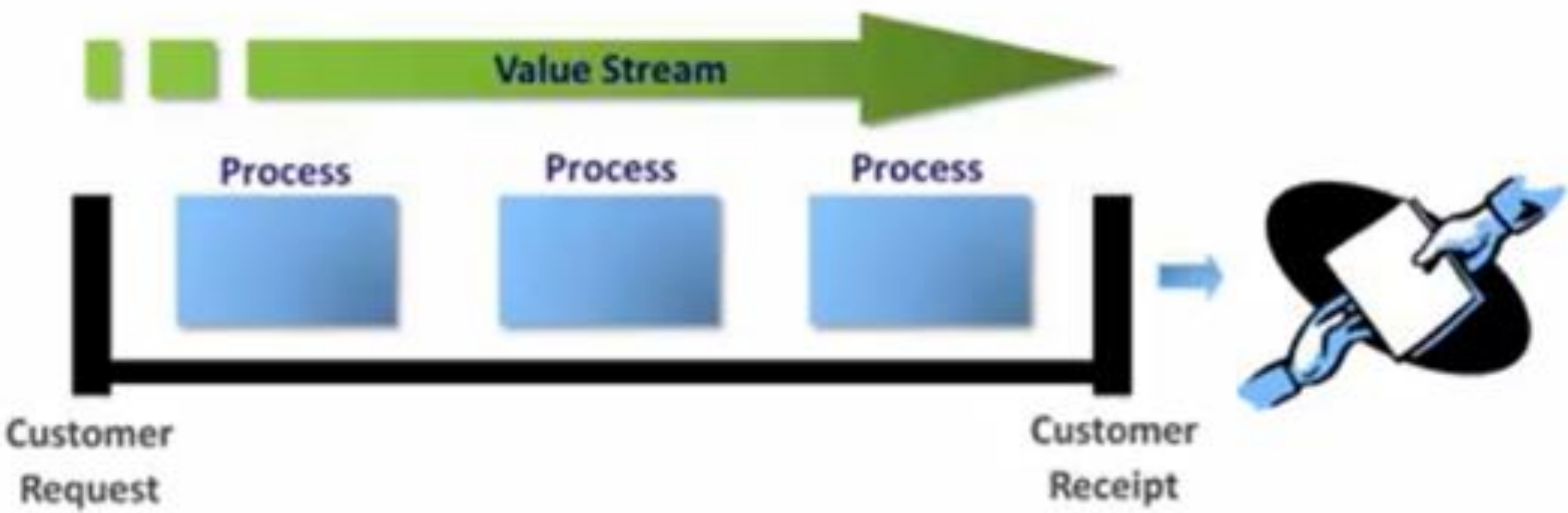


Steps in Value Stream Mapping

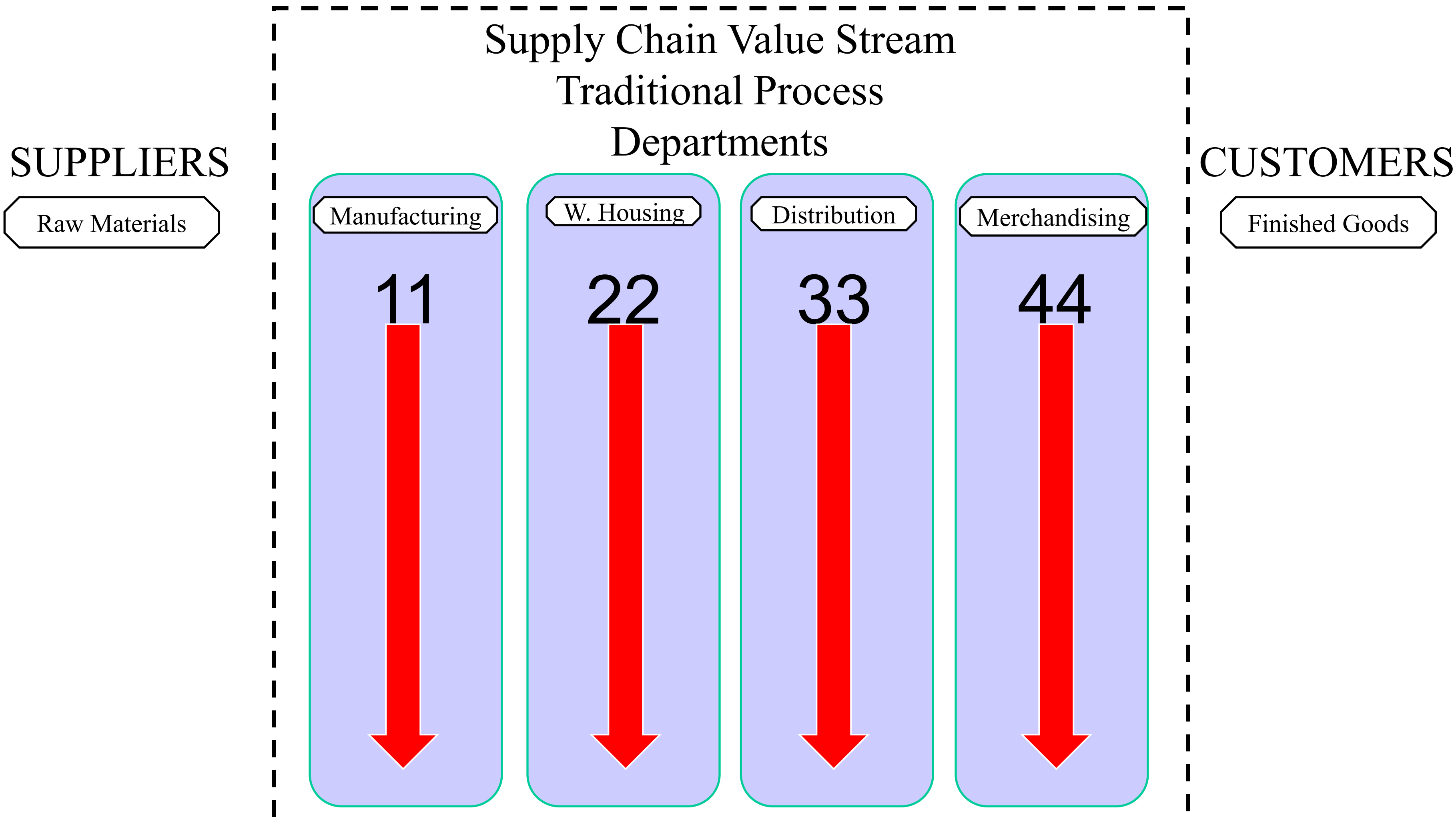


Value Stream Defined

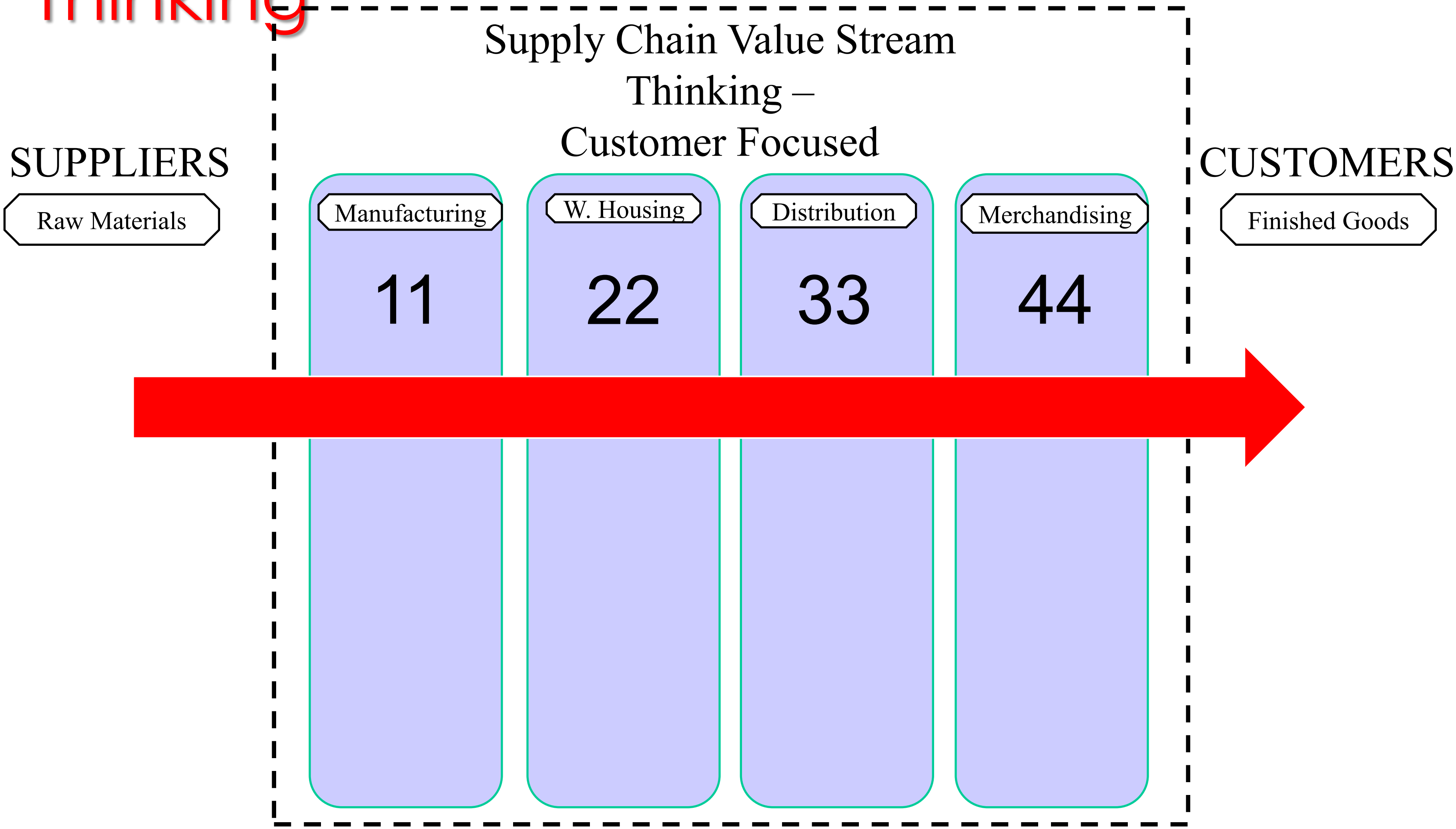
Value Stream: All of the activities required to transform a customer request into a good or service.

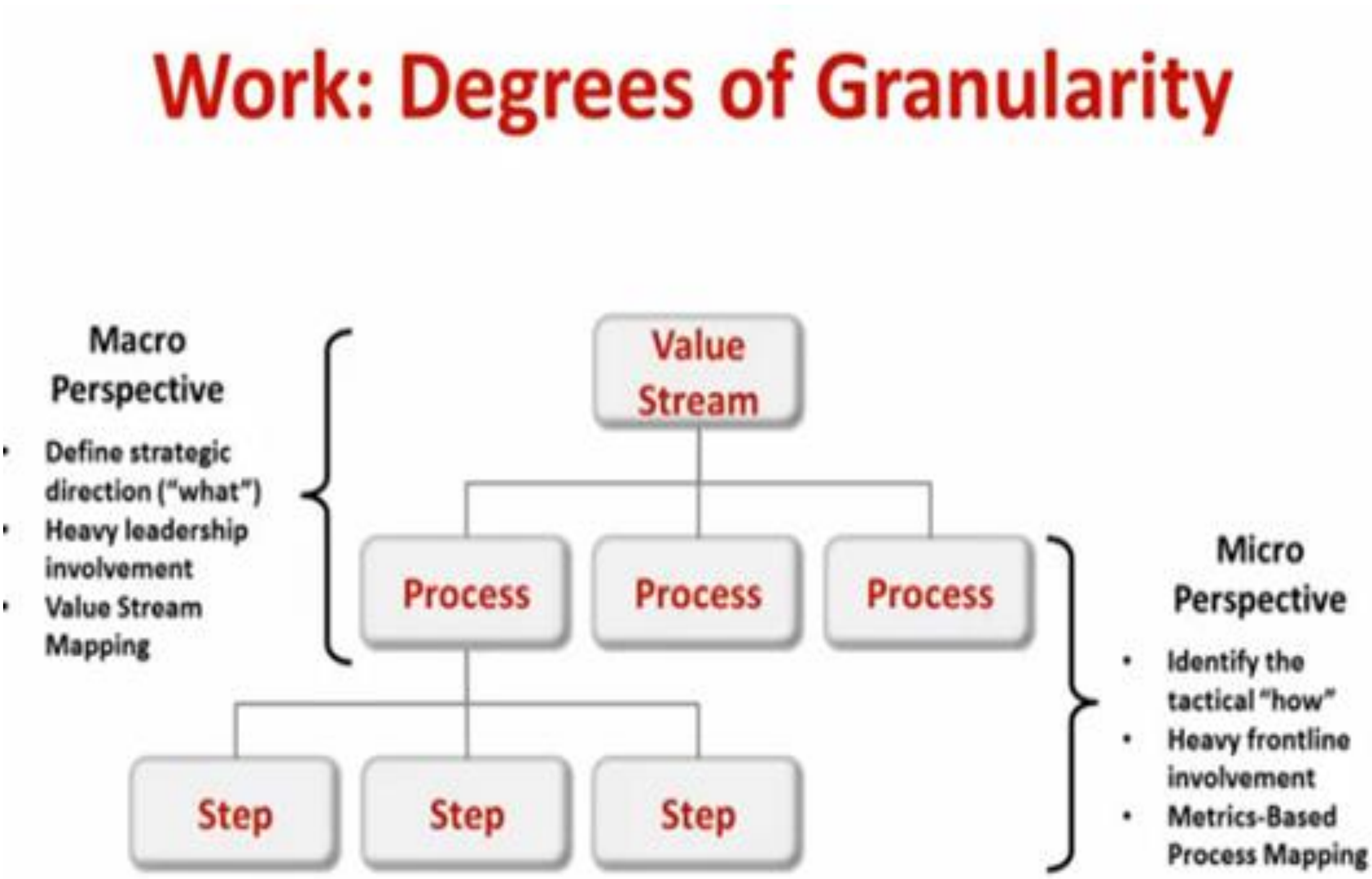


Value Stream – Traditional Thinking



Value Stream – Customer Focused Thinking

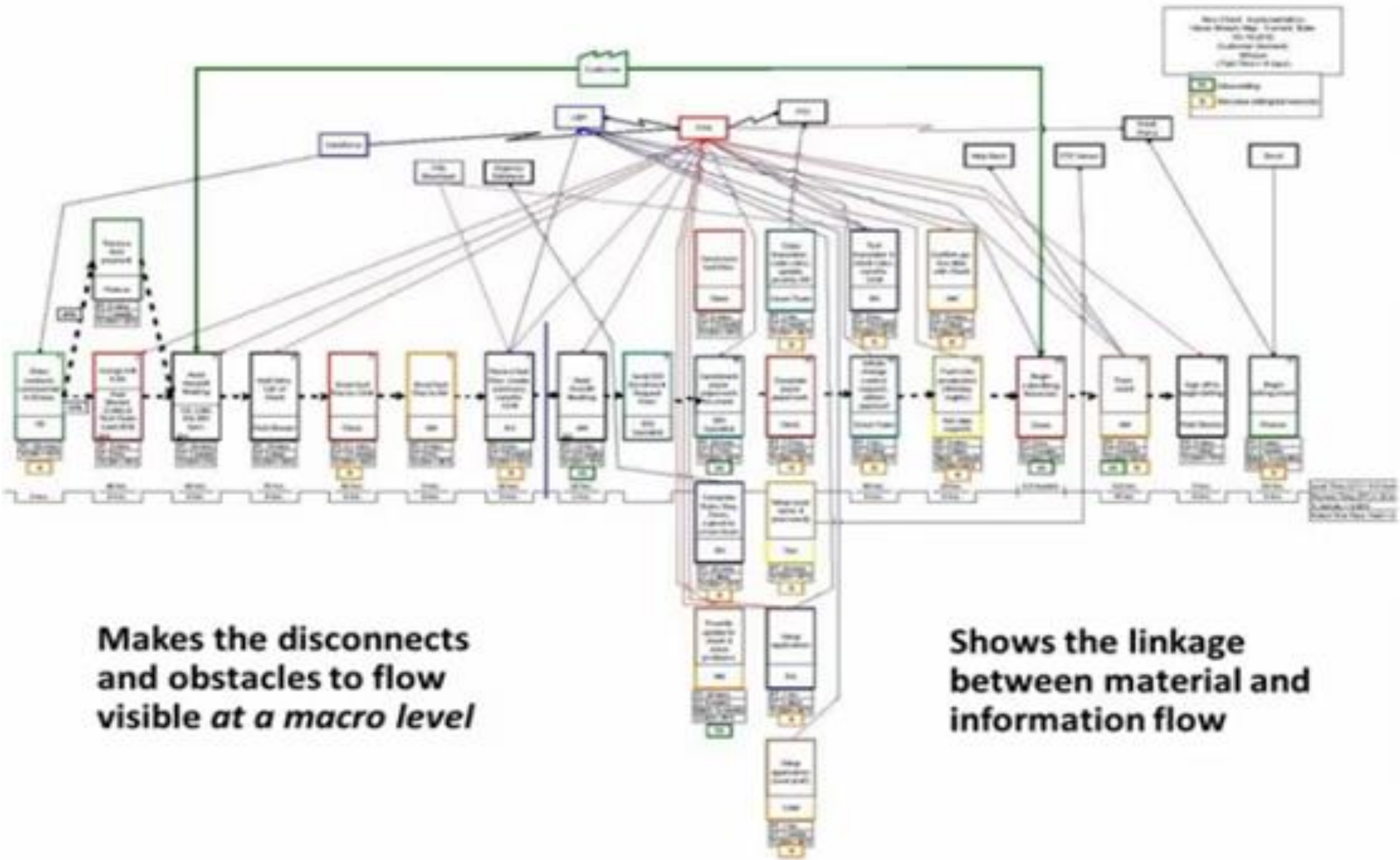



Work: Degrees of Granularity
Macro Perspective
• Define strategic direction ("what")
• Heavy leadership involvement
• Value Stream Mapping
Value Stream
Process
Process
Process
Step
Step
Step
Micro Perspective
• Identify the tactical "how"
• Heavy frontline involvement
• Metrics-Based Process Mapping

Value Stream Mapping Benefit: Seeing the Whole

60,000 foot view; Rooftop view

Value Stream Maps Serve as Visual "Storyboards"



Makes the disconnects and obstacles to flow visible *at a macro level*

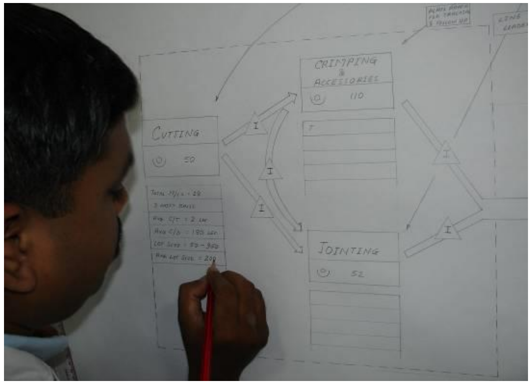
Shows the linkage between material and information flow

Value Stream Mapping Benefits

- Visual unification tool
- Connection to the customer
- Holistic systems-thinking methodology
- Simplification tool
- Practical means to drive continuous improvement
- Effective means to orient new hires

A Few Mapping Tips

- Always collect current-state information while walking along the actual pathways of material and information flows yourself.
- Begin with a quick walk along the entire door-to-door value stream.
- Begin at the shipping end and work upstream.
- Bring your stopwatch and do not rely on standard times or information that you do not personally obtain.
- Map the whole value stream yourself.
- Always draw by hand in pencil.



Current State Map

Step 1: Select a Product Family

Step 2: Form a Team

Step 3: Understand Customer Demand

Step 4: Map the Process Flow

Step 5: Map the Material Flow

Step 6: Map the Information Flow

Step 7: Calculate Total Product Cycle Time

Step 1: Select a Product Family

- Identify your product families from the customer end of the value stream.
- A family is a group of products that pass through similar processing steps and over common equipment.
- If your product mix is complicated, create a matrix with assembly steps and equipment on one axis, and your products on the other axis.

Step 1: Select a Product Family

PRODUCTS	ASSEMBLY STEPS & EQUIPMENT 1	2	3	4	5	6	7	8	9
A	X	X	X		X	X			
B	X	X	X	X	X	X			
C	X	X	X		X	X	X		
D		X	X	X	X			X	X
E		X	X	X				X	
F	X		X		X	X	X		X
G	X		X	X					

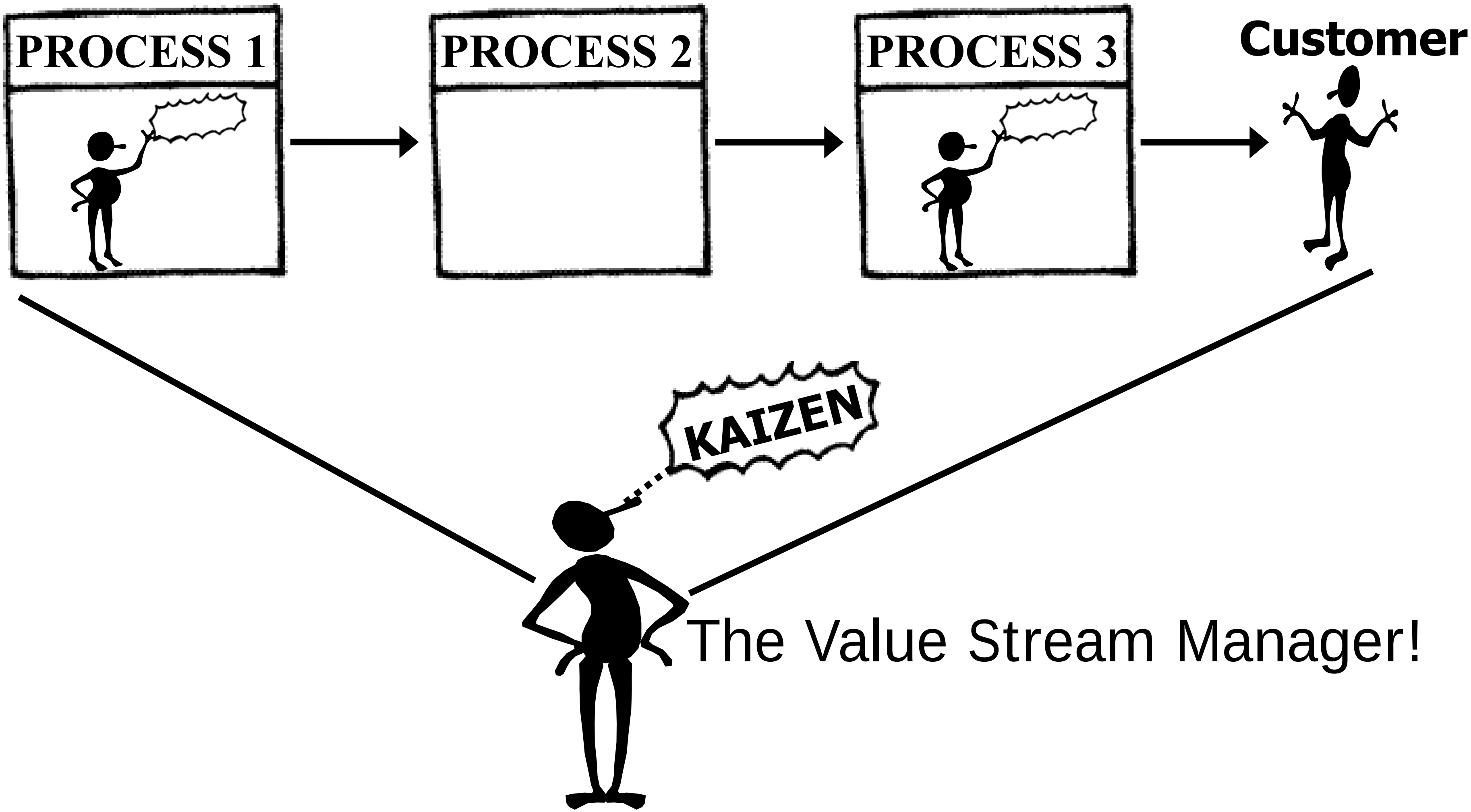
PRODUCT FAMILY

Step 2: Form a Team

- Select a cross-functional team
- Select team members who are familiar with the product
- Ensure that team members are trained in the use of VSM
- Designate a Value Stream Manager

THIS IS CRITICAL

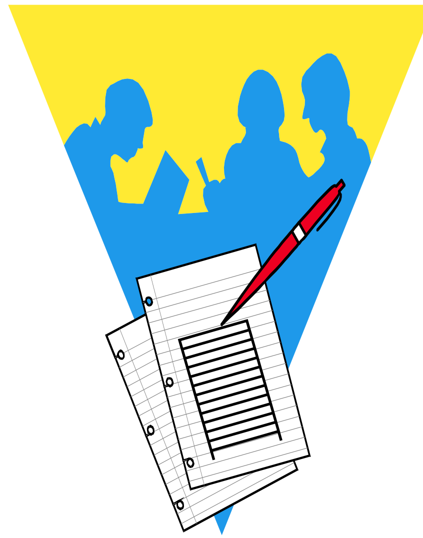
Who is responsible for the Value Stream?



The Value Stream Manager!

Data Collection

Data To Collect



- Shipping/Receiving schedules
- Pack sizes at each process
- Demand rates by process (Takt Time)
- Working hours and breaks
- Inventory Points (location & size)
- How Operations are scheduled

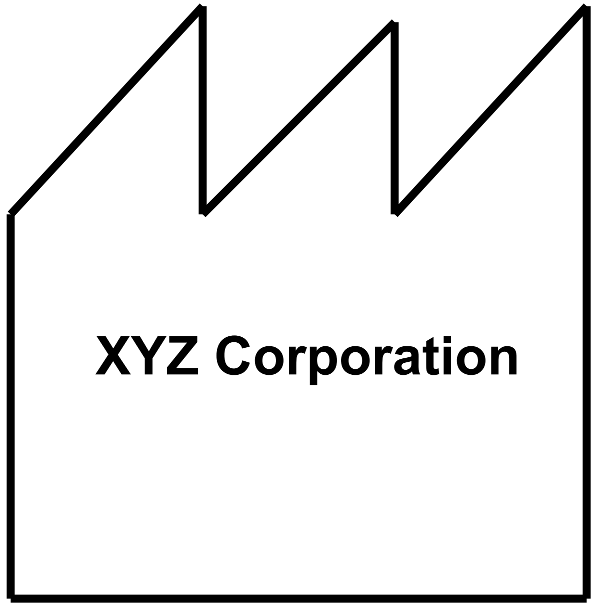
- Scrap
- Rework
- Downtime

- Work-in-process inventory
- Overtime per week
- Process cycle times
- Number of product variations at each step
- Batch (lot) sizes
- Changeover times
- Changeover frequencies

Step 3: Understand Customer Demand

- Mapping starts with the customer requirements.
- Represent the customer's assembly plant with a factory icon, placed in the upper right-hand portion of the map.
- Underneath this icon, draw a data box recording the requirements of the customer.

VSM Icon : Outside Source



Outside Sources

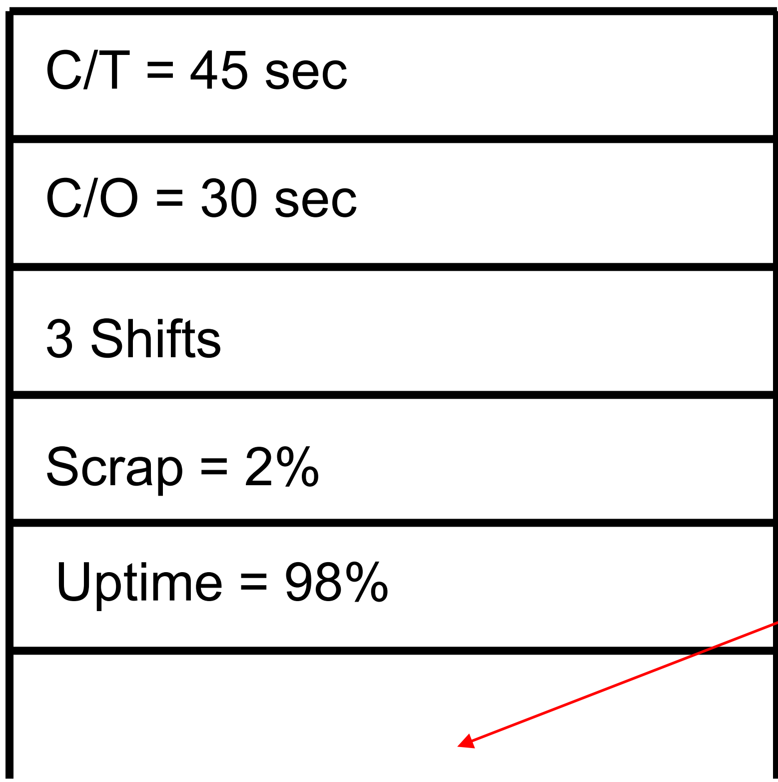
Suppliers

Customers

Ext. Job Shops

VSM Icon: Data Box

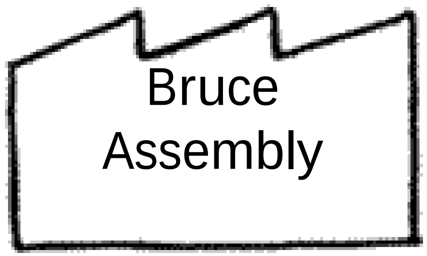
Data Box



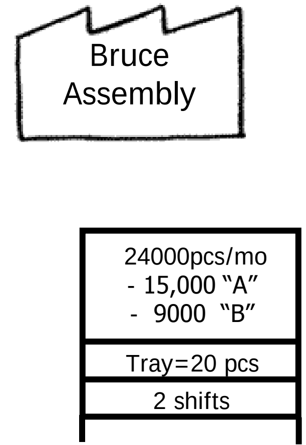
Used to record information concerning A manufacturing process, department, customer, etc.

Open at Bottom For Additional Data

Step 3: Understand Customer Demand



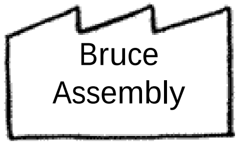
Outside Source - Customer



Step 3: Understand Customer Demand

24000pcs/mo -15000 type A - 9000 type B
Tray=20 pcs
2 shifts

Data Box

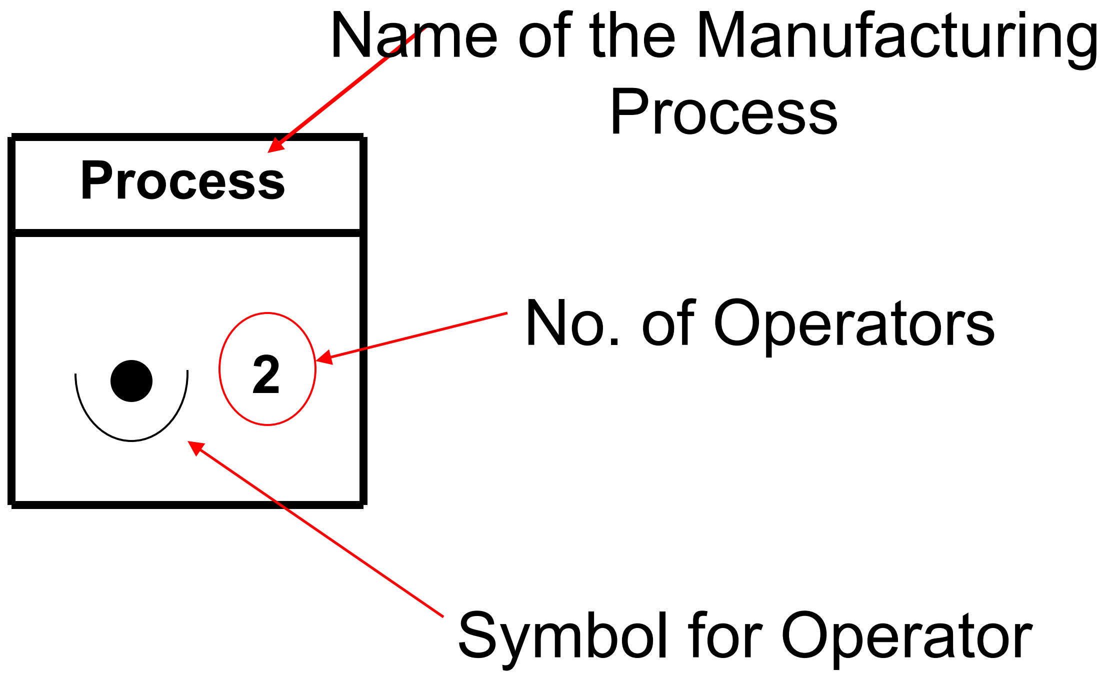


24000pcs/mo - 15,000 "A" - 9000 "B"
Tray=20 pcs
2 shifts

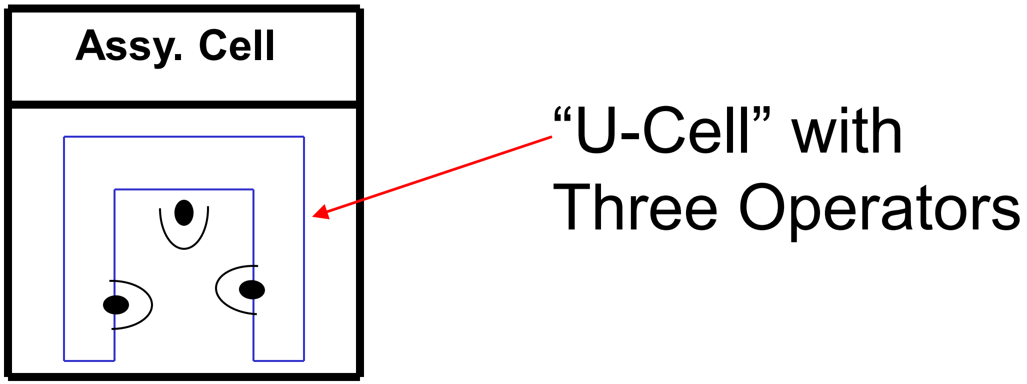
Step 4: Map the Process Flow

- Draw the basic production processes by using a process box.
- The process boxes must be arranged in the sequence of their occurrence.
- Draw the data box for each production process recording the cycle time, changeover time, reliability, available work time, etc. for each individual process.

VSM Icon : Process

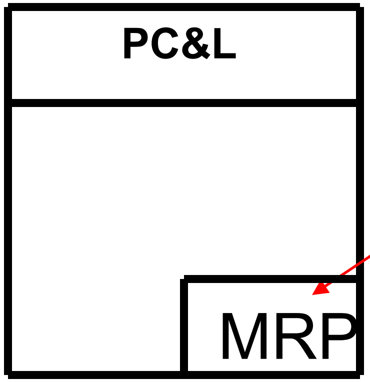


VSM Icon : Process



One process box equals an area of flow. All processes should be Labeled.

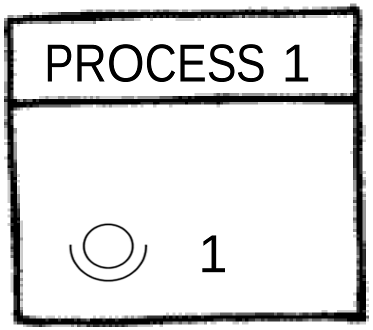
VSM Icon : Process

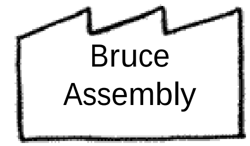


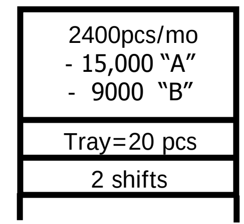
Department runs
MRP Software
For Material Planning

Also used for departments such as Production Control, sales &

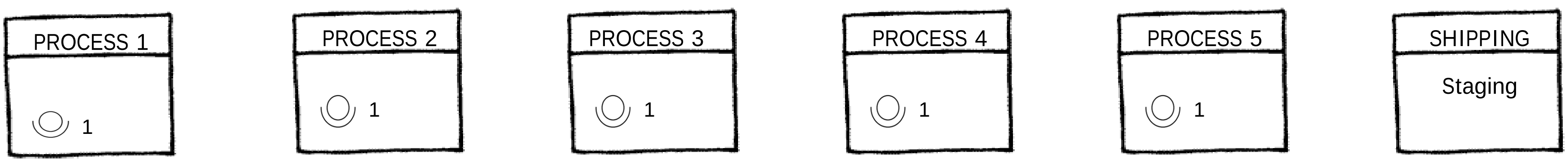
Step 4: Map the Process Flow



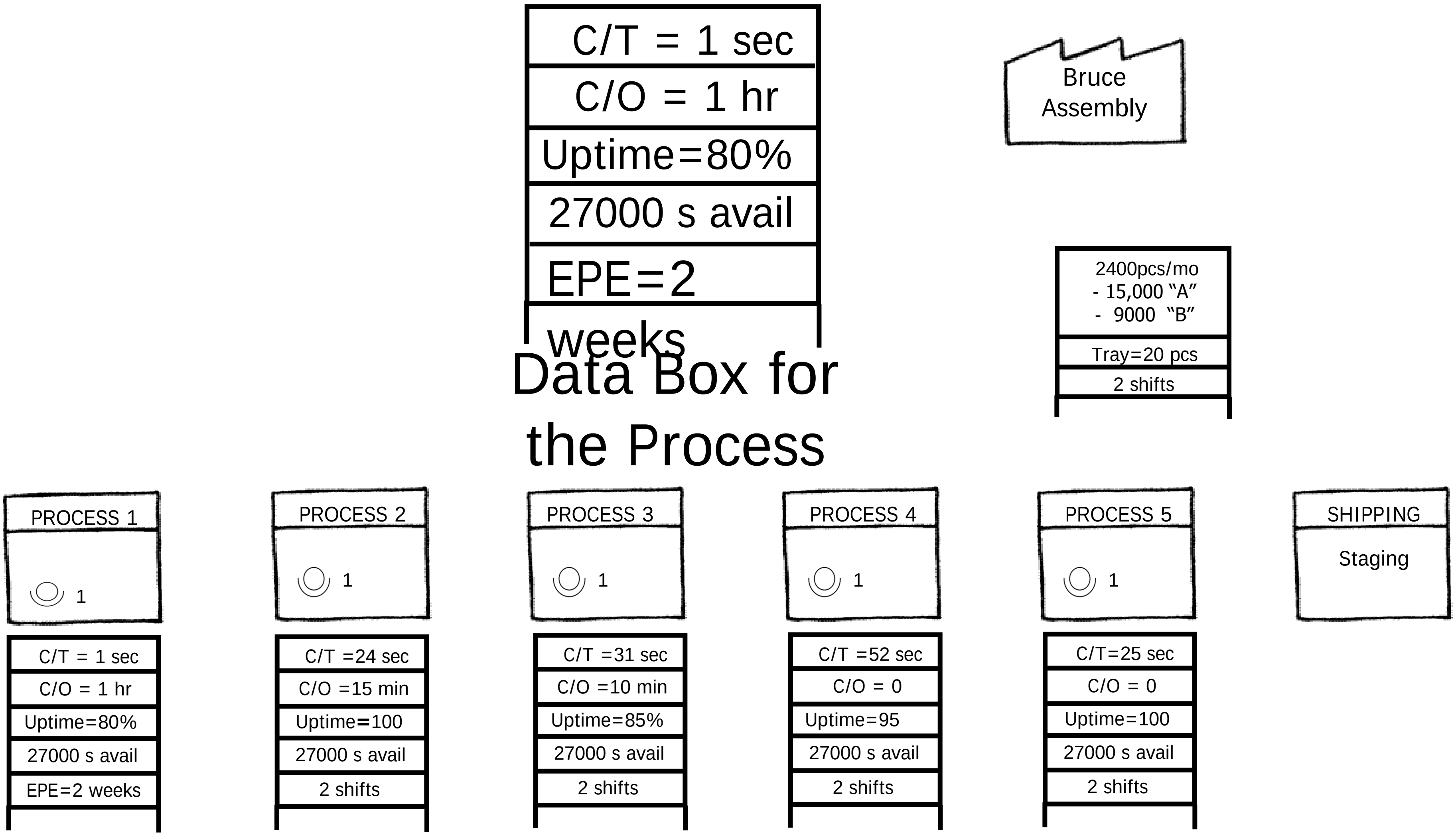




Manufacturing Process



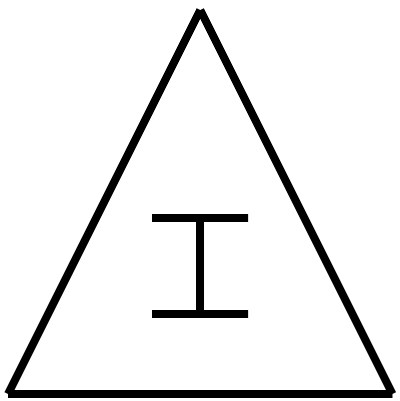
Step 4: Map the Process Flow



Step 5: Map the Material Flow

- Material Flow is drawn from left to right on the bottom half of the map in the order of processing steps, not according to the physical layout of the plant.

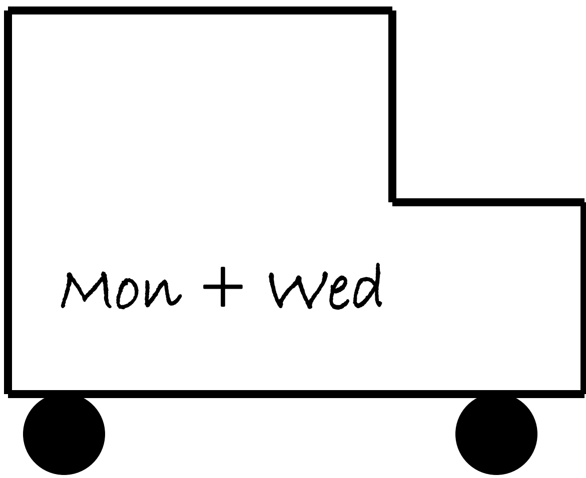
Inventory



330 pieces
1 Day

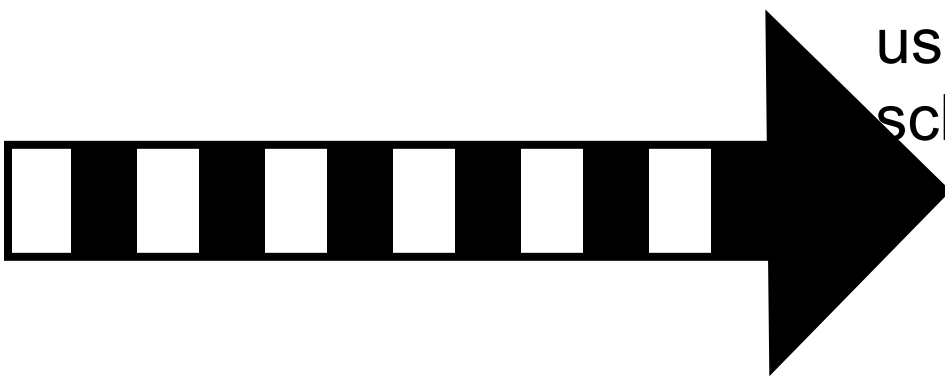
Count and time should be Noted.

Truck Shipment



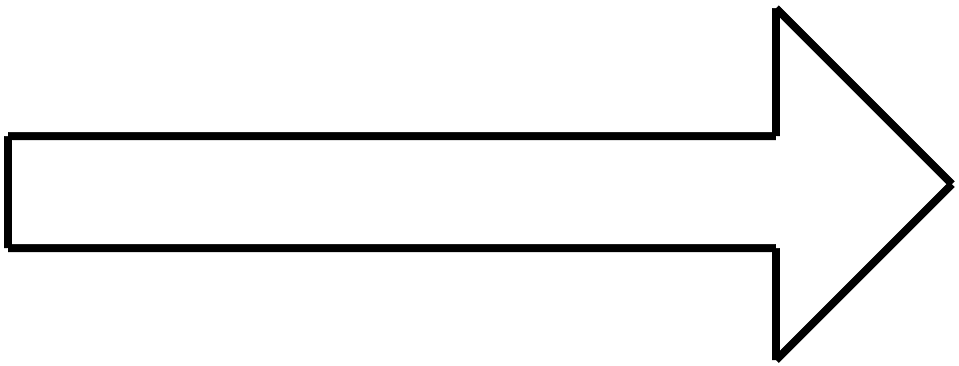
Note frequency of shipments.

Movement of production Material by PUSH

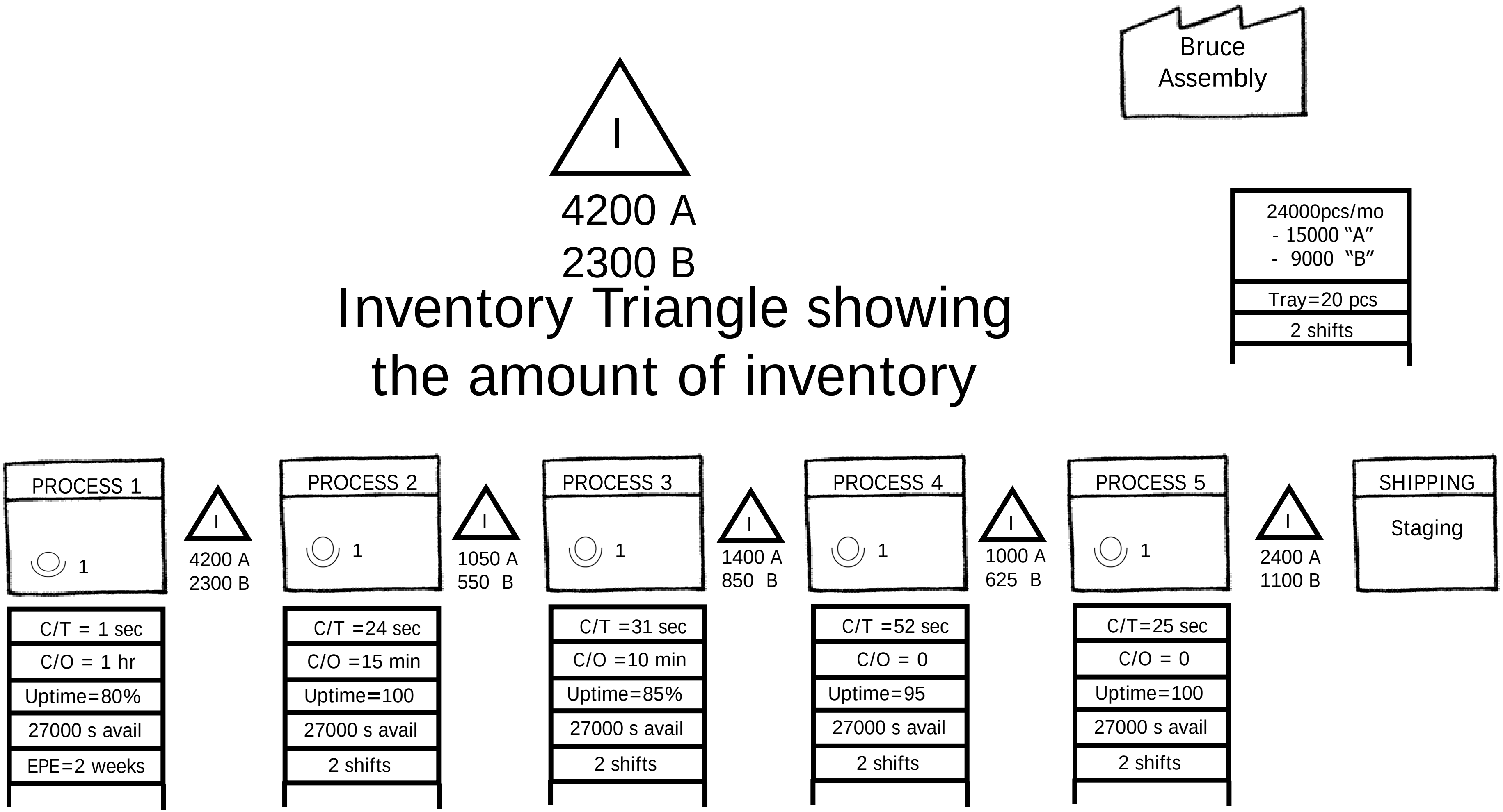


Material that is produced and moved forward before the next process needs it; usually based on a schedule.

Movement of finished
Goods to the customer

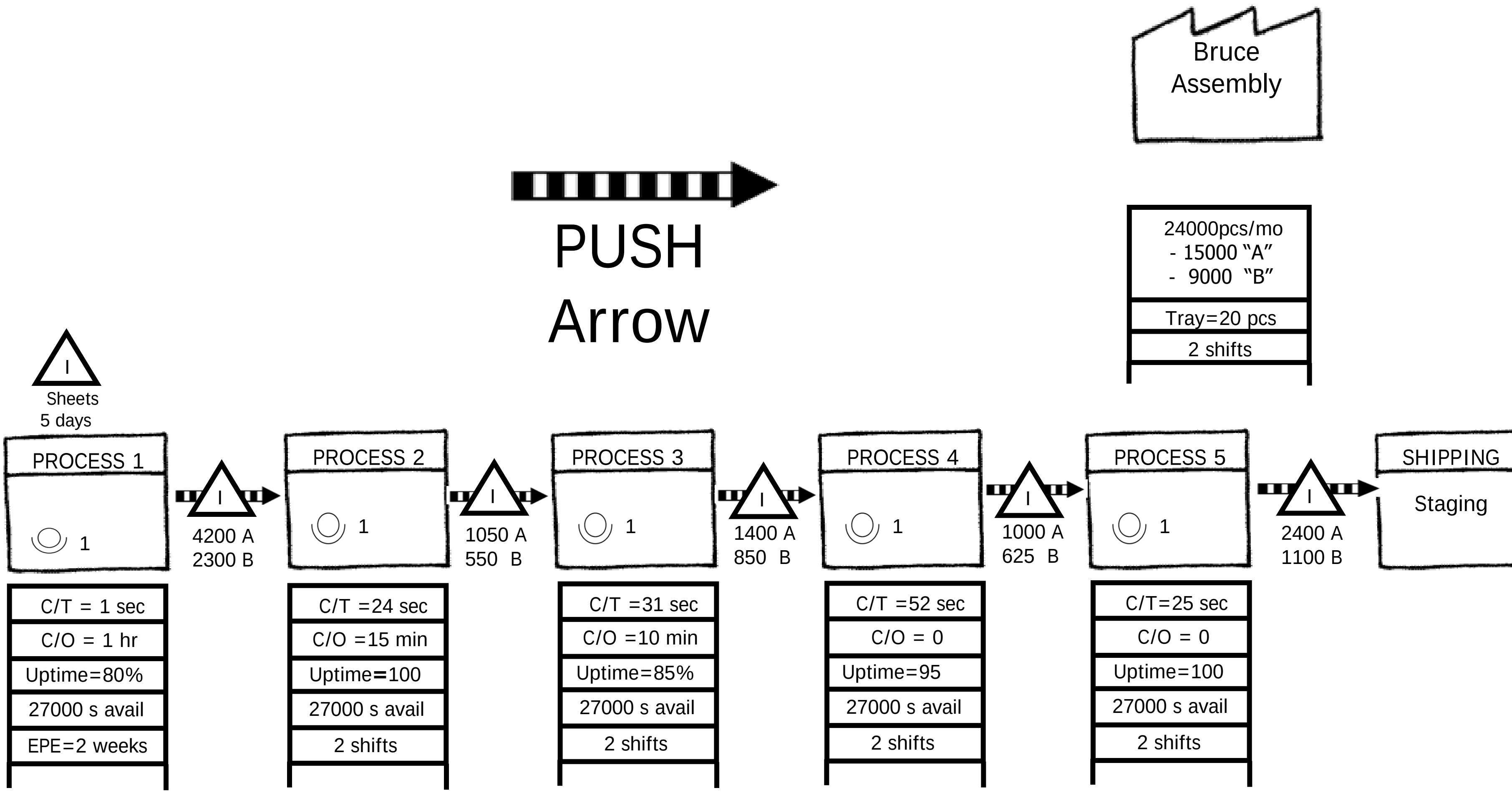


Step 5: Map the Material Flow

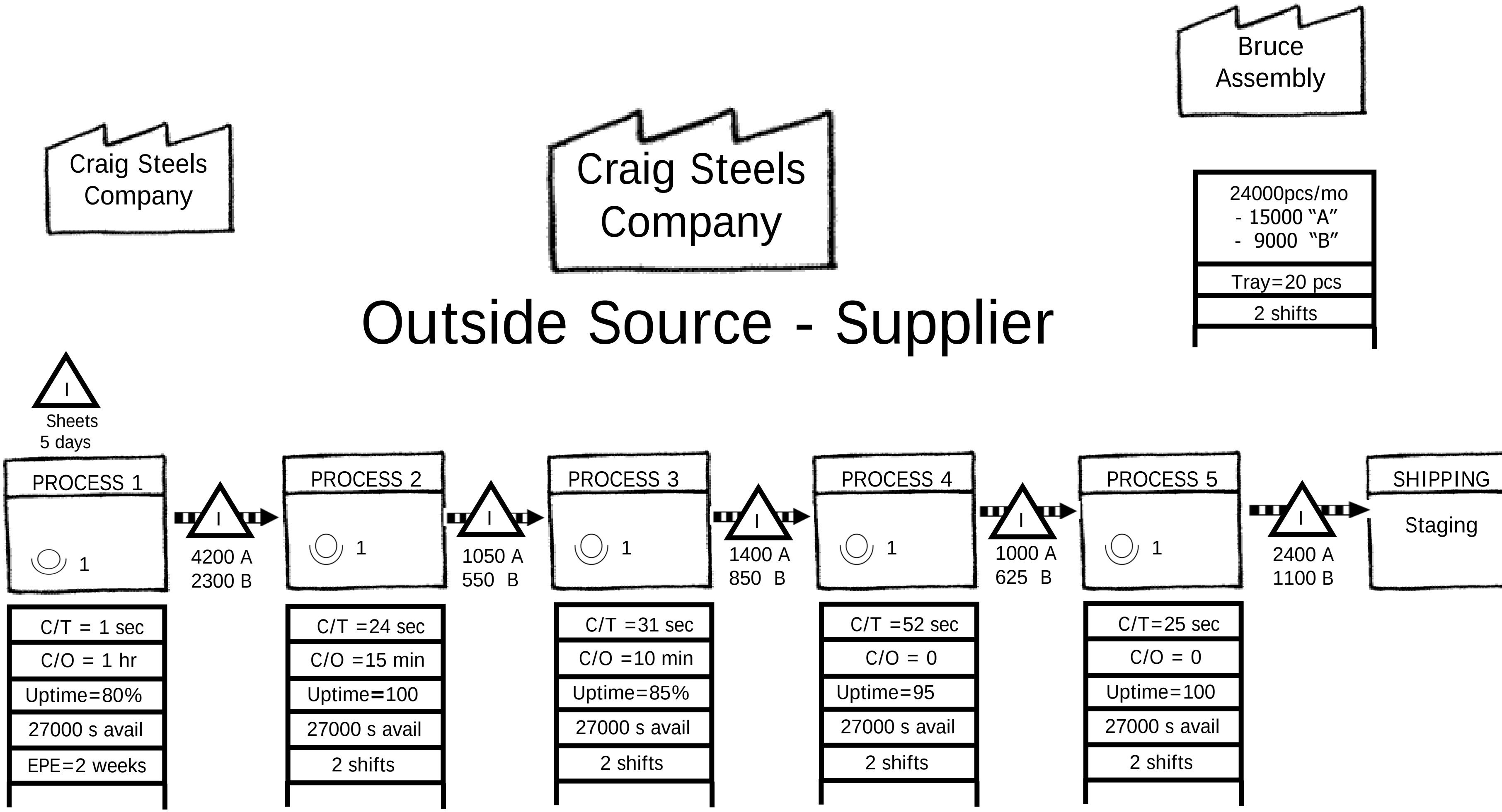


Inventory Triangle showing the amount of inventory

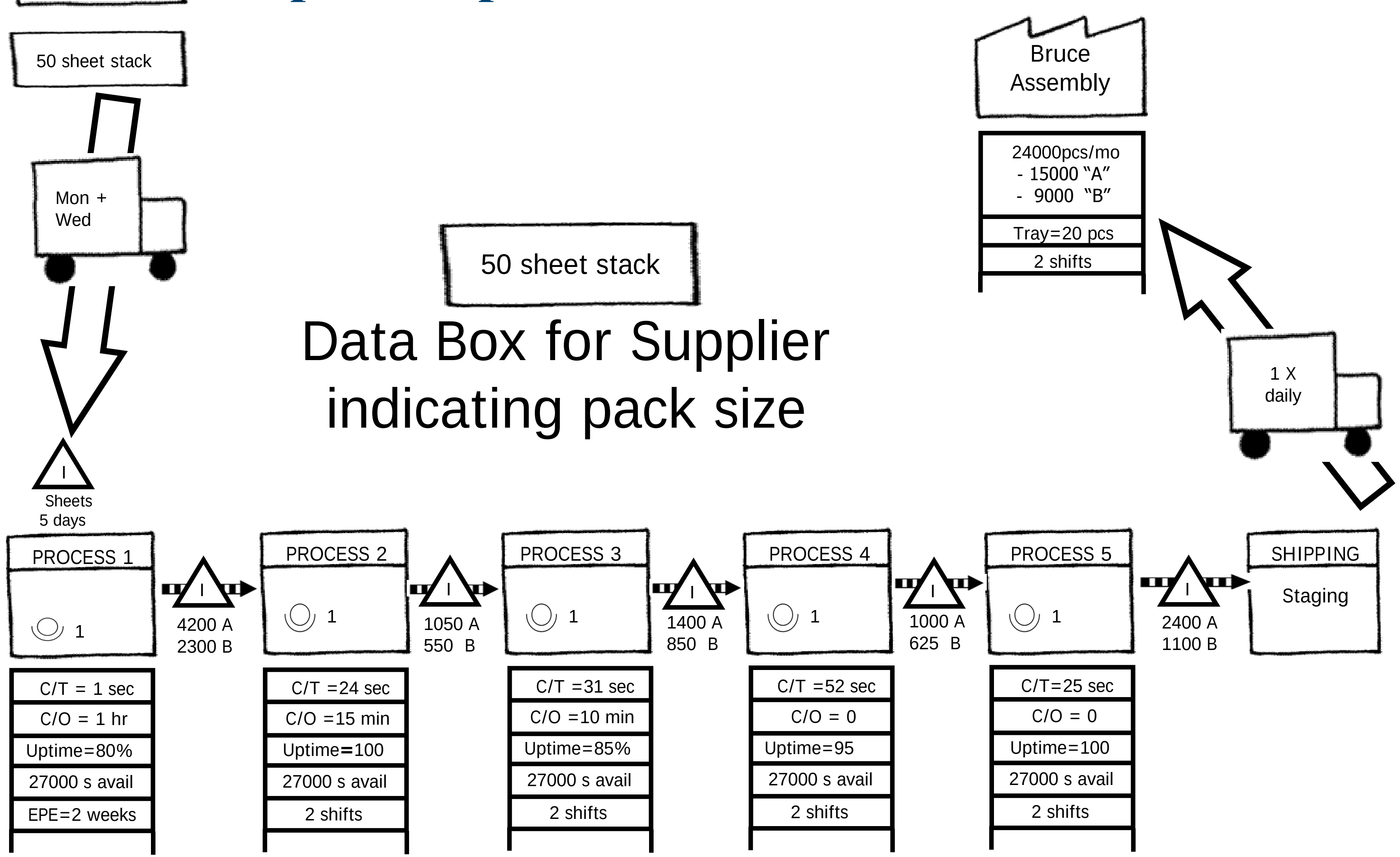
Step 5: Map the Material Flow



Step 5: Map the Material Flow



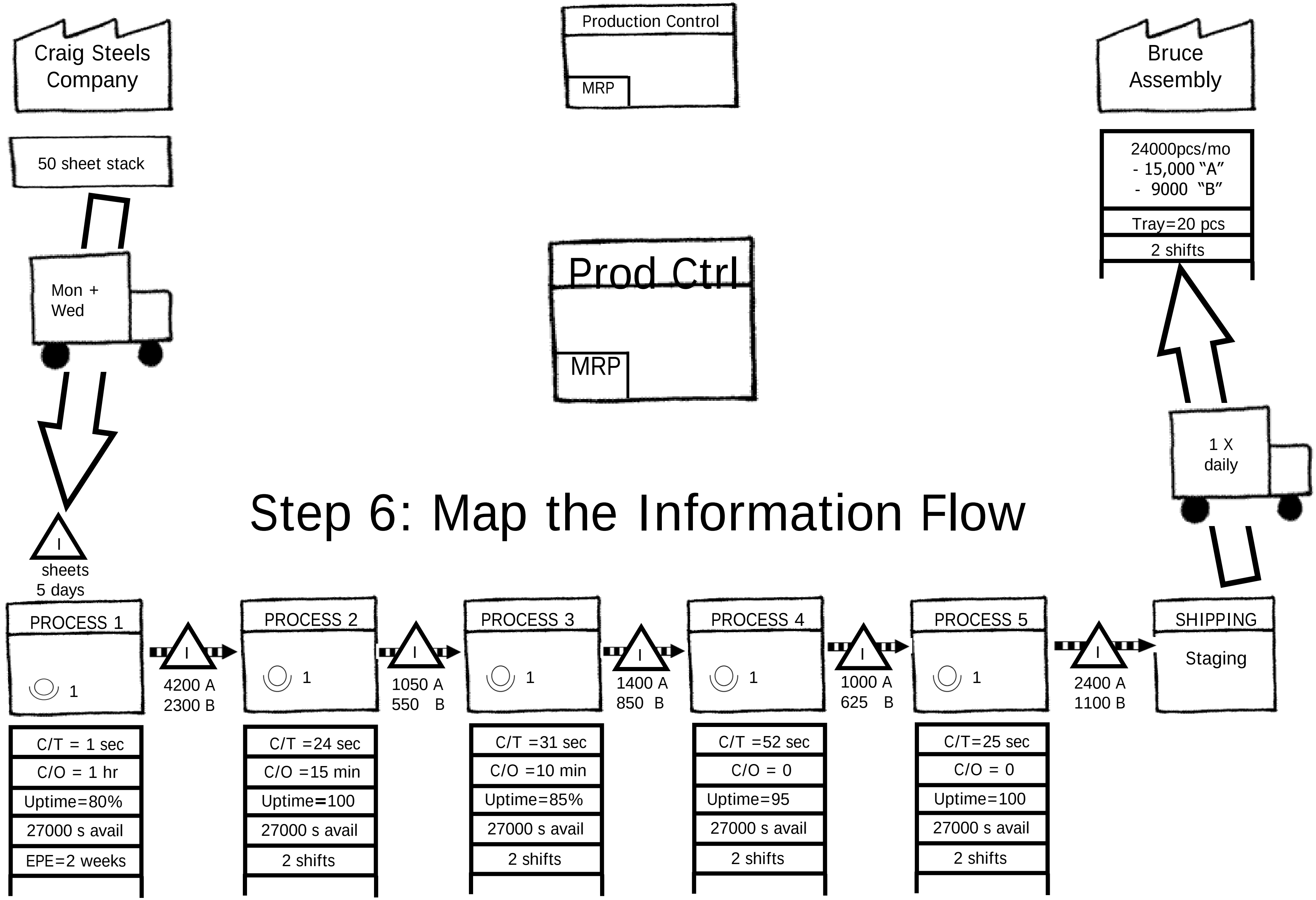
Step 5: Map the Material Flow



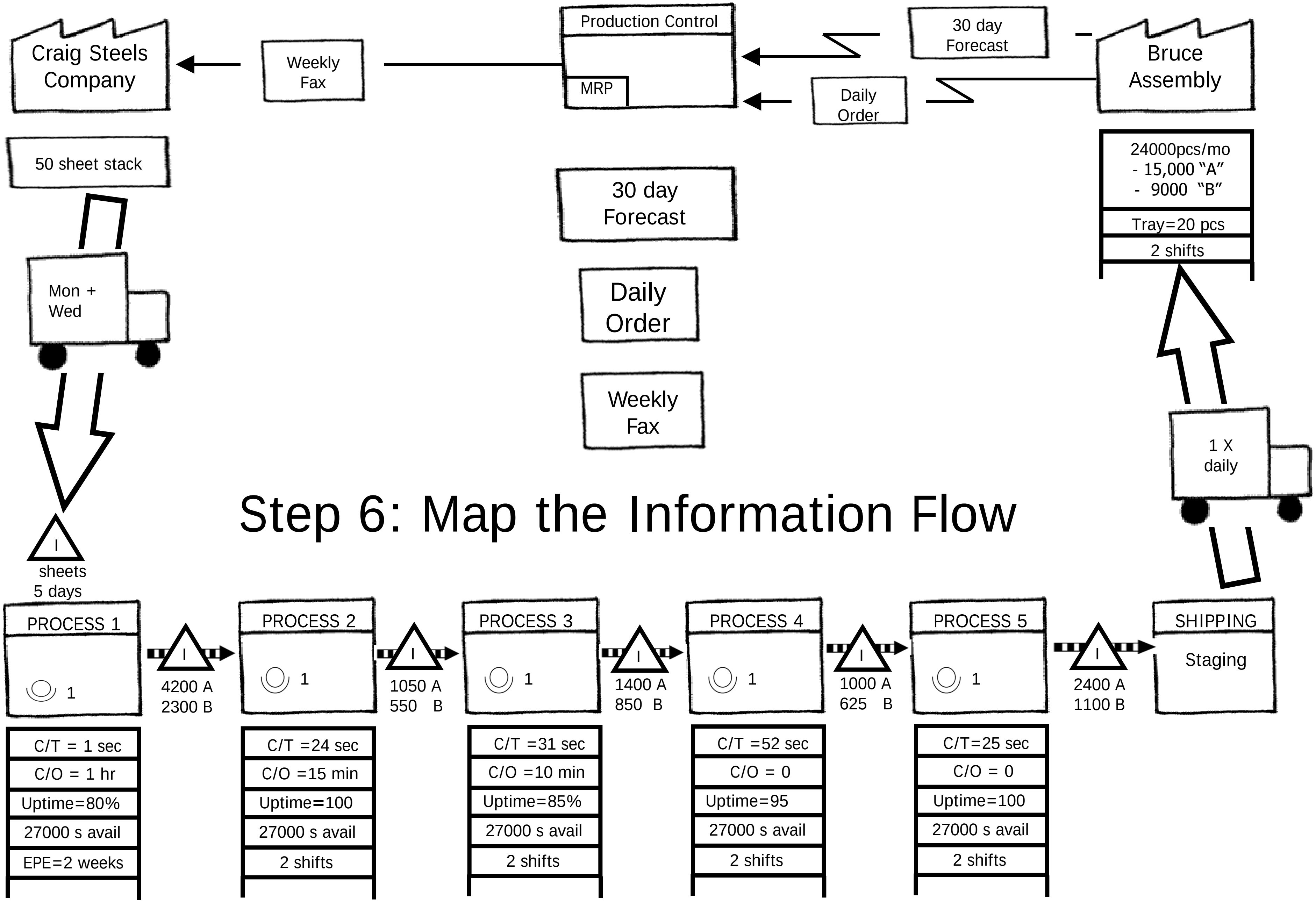
Step 6: Map the Information Flow

- The information flow is drawn from right to left in the top half of the map.

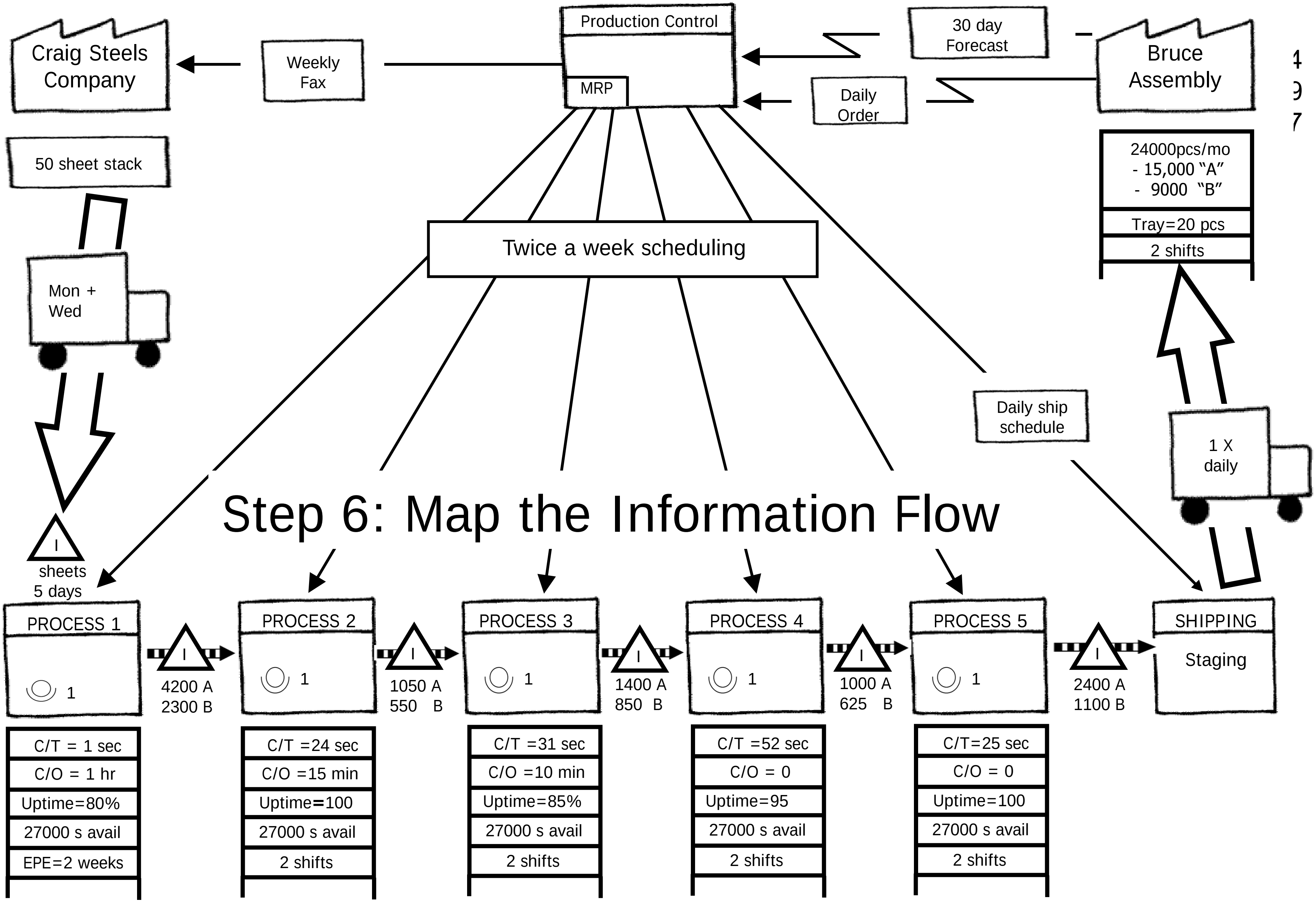
Step 6: Map the Information Flow



Step 6: Map the Information Flow



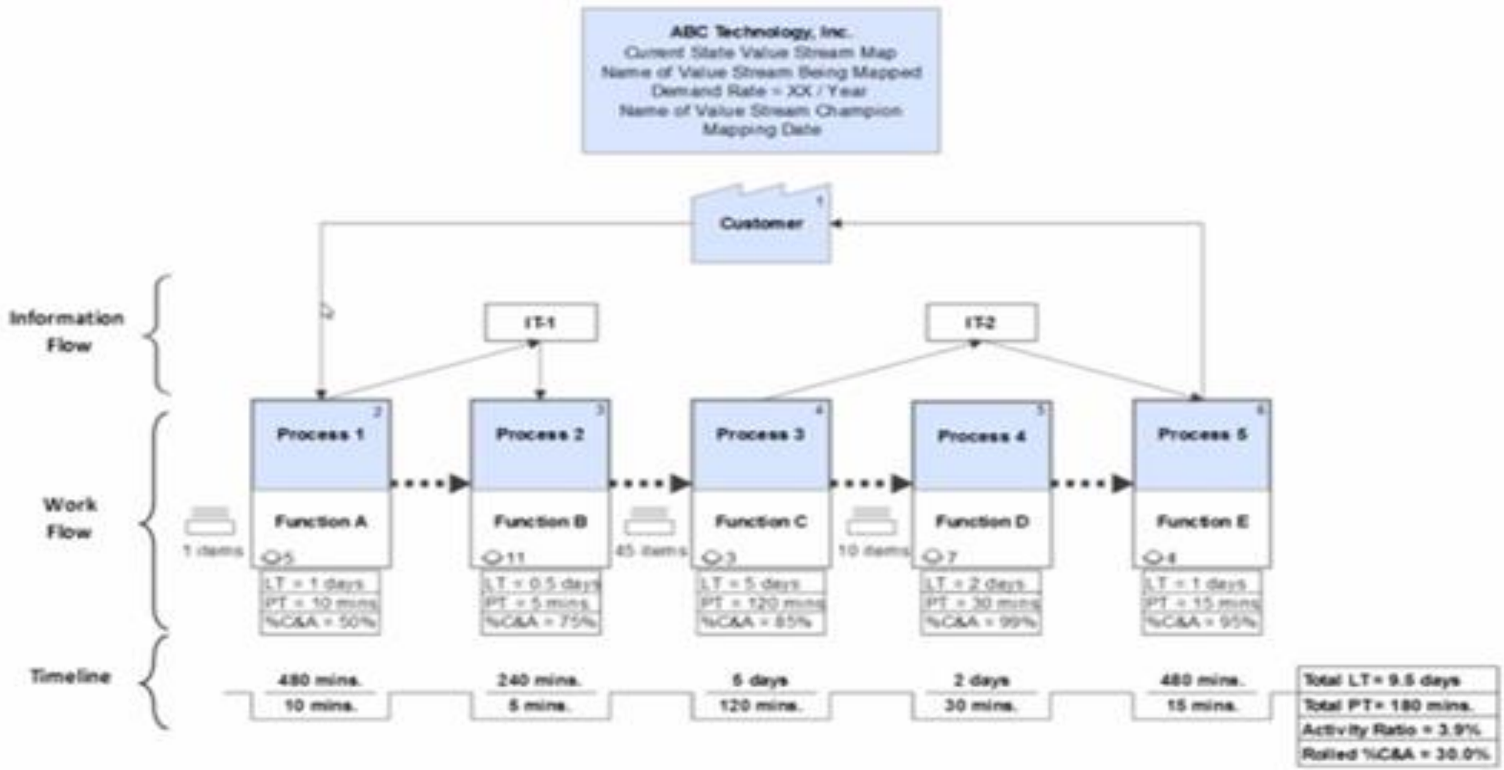
Step 6: Map the Information Flow



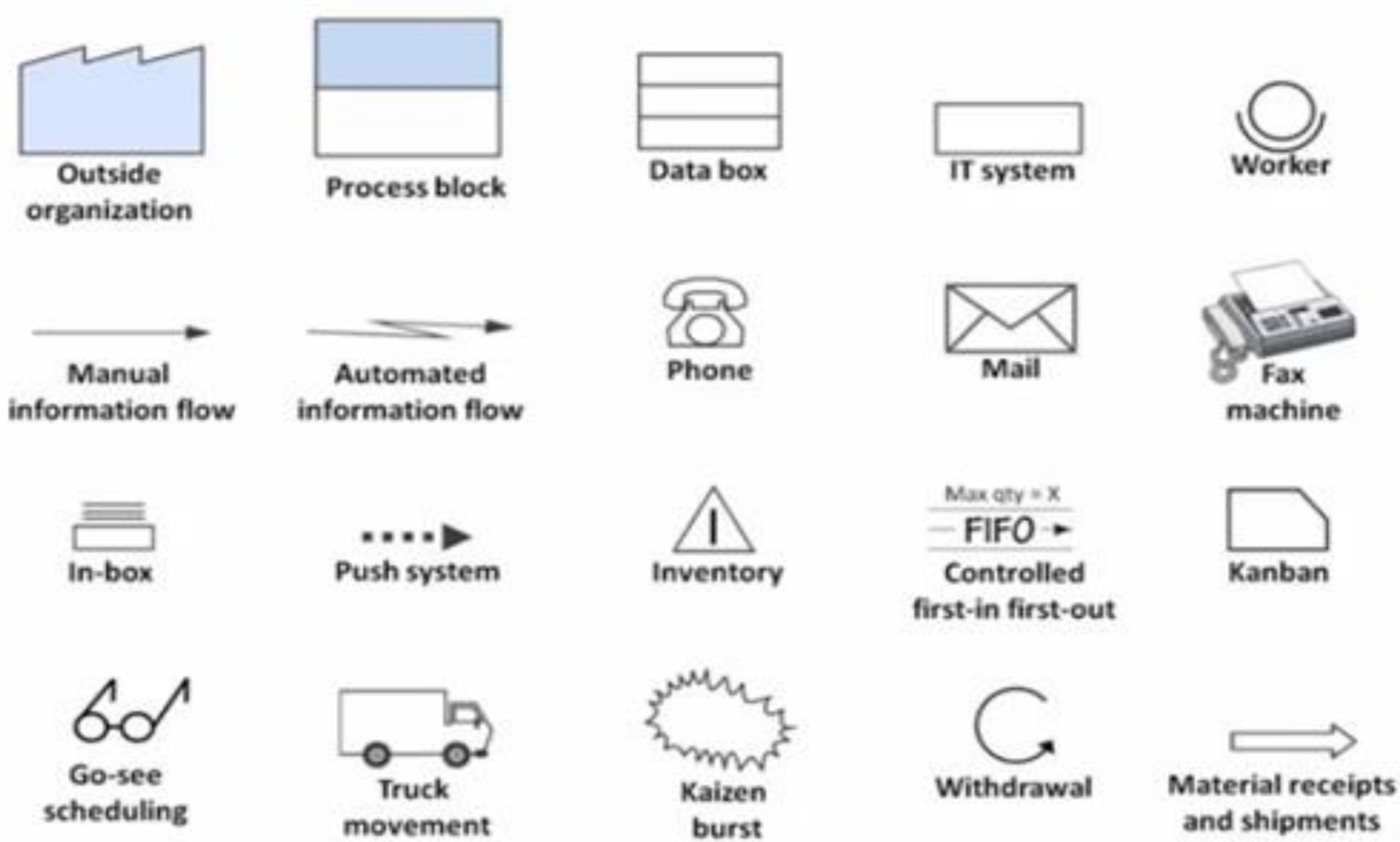
Step 7: Calculate Total Product Cycle Time

- Draw a timeline under the process boxes and inventory triangles to compile the production lead time.
- Production lead time is the time it takes one part to make its way through the shop floor, beginning with arrival as raw material through to shipment to the customer.
- Next, add up only the value-adding (processing) times for each process.
- Compare the value added to total lead time.

Components of a Value Stream Map



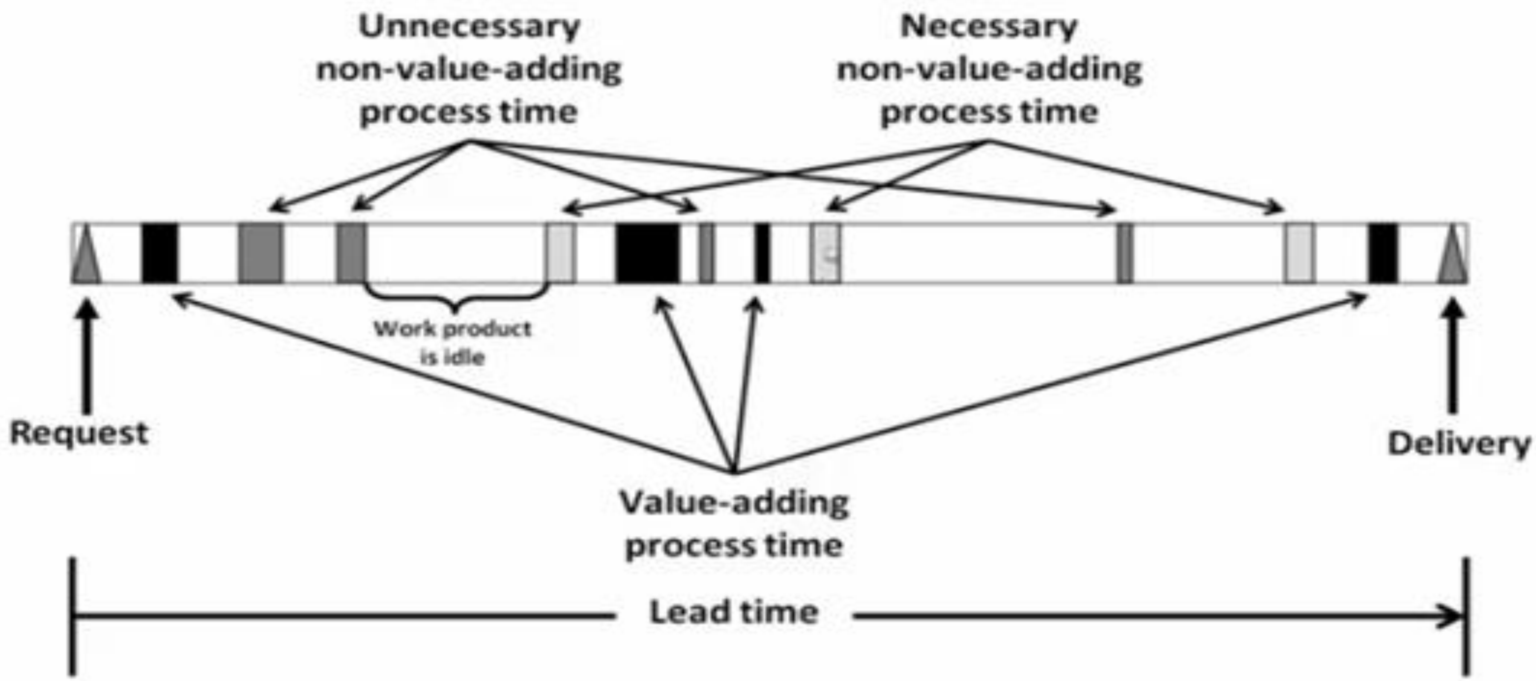
Common value stream mapping icons



Key Metrics: Time

- Process time (PT)
  - The time it takes to actually perform the work, if one is able to work on it uninterrupted
  - Includes task-specific doing, talking, and thinking
  - aka "touch time," work time, cycle time
- Lead time (LT)
  - The elapsed time from the time work is made available until it's completed ***and passed on*** to the next person or department in the chain
  - aka throughput time, turnaround time, elapsed time
  - *Includes* Process Time, not merely waiting time.

Process time versus lead time across the value stream



Key Metrics: Quality

- %Complete and Accurate (%C&A)
  - % of incoming work that's "usable as is"; the downstream customer can perform task without having to "CAC":
    - **C**orrect information or material that was supplied
    - **A**dd information that should have been supplied
    - **C**larify information that should have or could have been clearer
  - Determined by the person receiving the input; metric goes on the output block.
  - Measured by the immediate downstream customer and all subsequent downstream customers.
  - Similar to first pass yield in manufacturing.

Summary Metrics: Time

- Activity Ratio (AR)
  - The percentage of time anything is being done to the work passing through the system (whether value-adding or non-value-adding)
  - $AR = (\sum PT \div \sum LT) \times 100$
  - $100 - AR$ = % Time Work is Idle
  - Common current state finding = 1-10% (across value stream)
  - Could also calculate %VA to show proportion of value-adding time (often significantly lower than AR).

Summary Metrics: Quality

- Rolled Percent Complete & Accurate (Rolled %C&A)
  - The percent of value stream output that passes through the process "clean," with no "hiccups," no rework required.
  - Rolled %C&A = (%C&A x %C&A x %C&A...) x 100
  - Example: (0.80 x 0.50 x 0.99 x 0.75) x 100 = 29.7%
  - Common current state finding = 0-15%

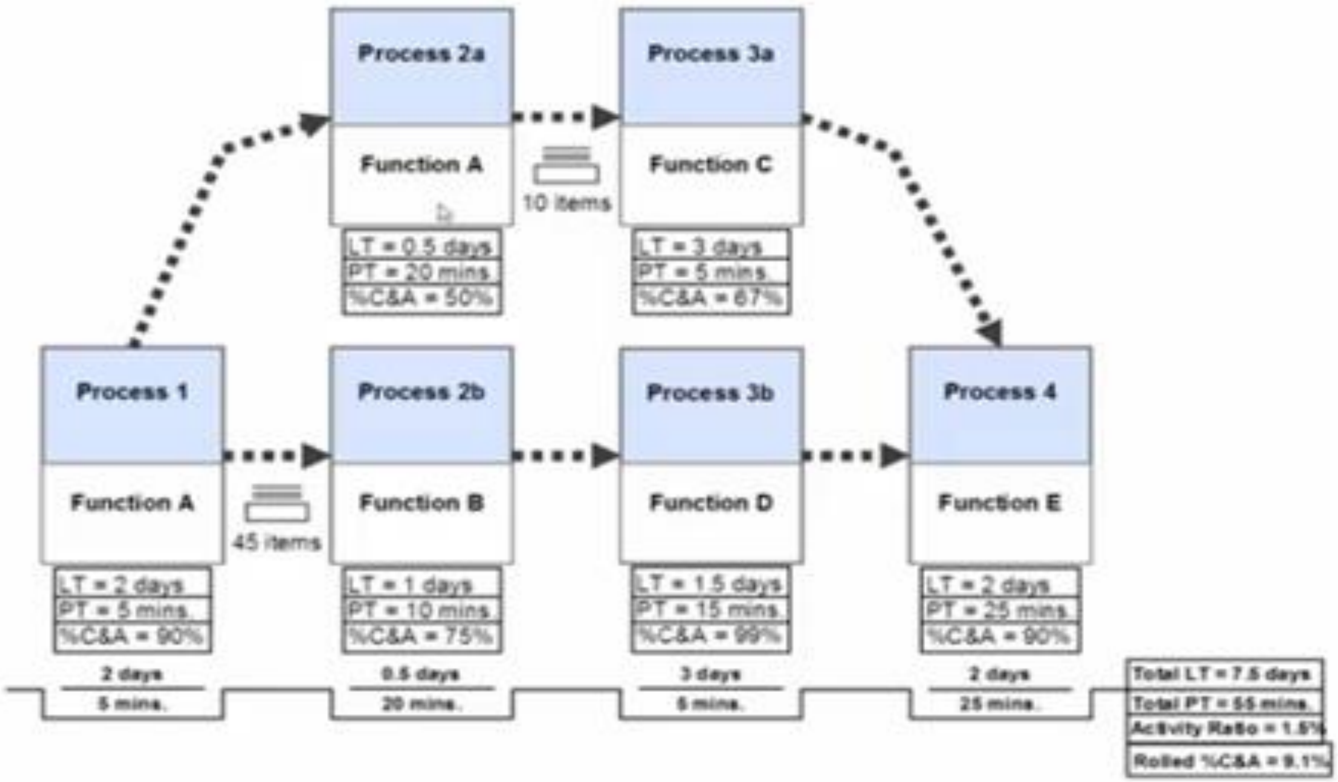
Summary Metrics: Labor Requirements

- Total PT
  - Sum of ***all*** activities, not just critical path
- Labor Requirements

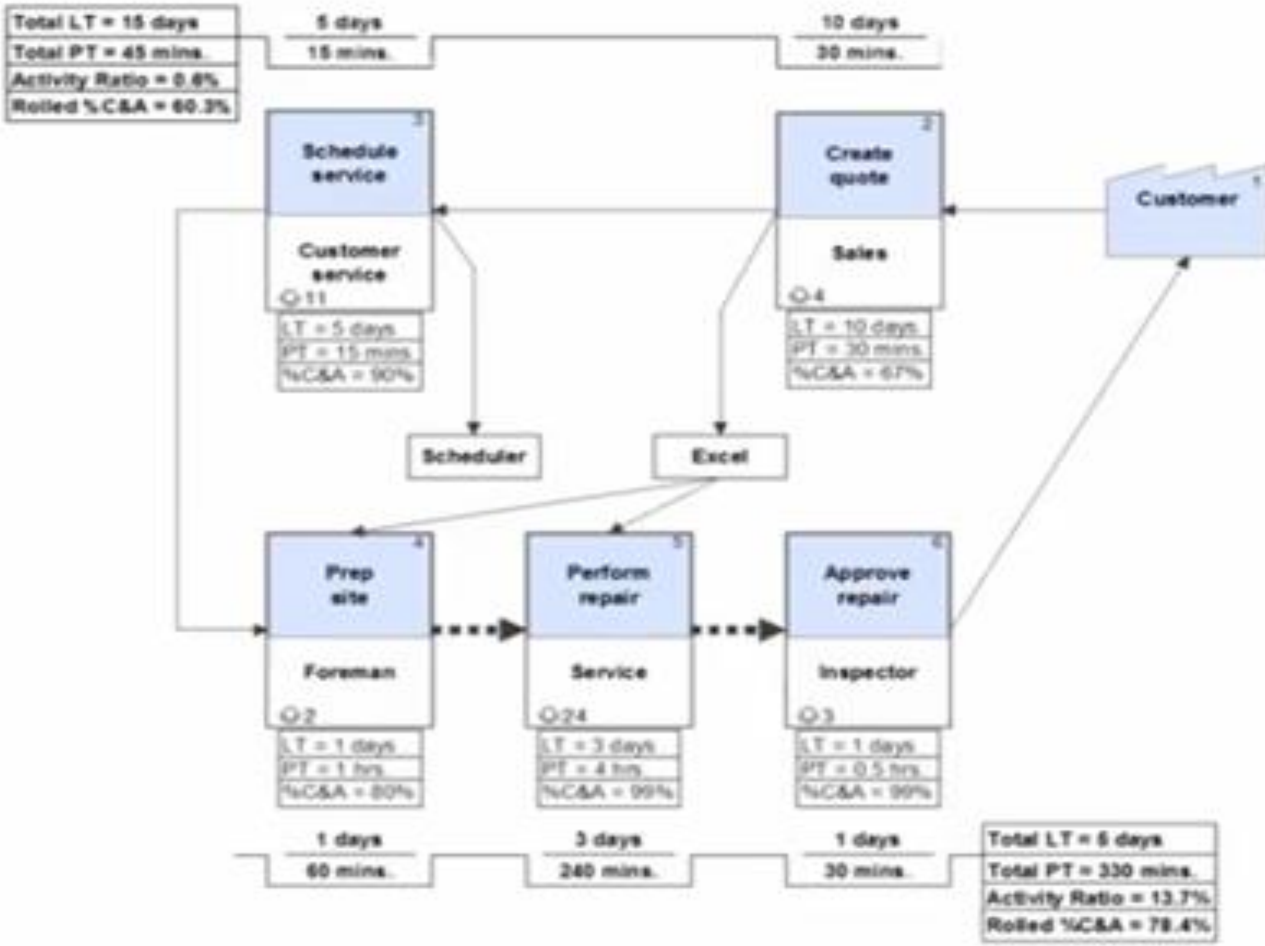
$$\textbf{\# FTEs} = \frac{\text{Total PT (in hrs) X \# occurrences/year}}{\text{Available work hrs/year}}$$

Freed Capacity = Current State FTEs – Future State FTEs

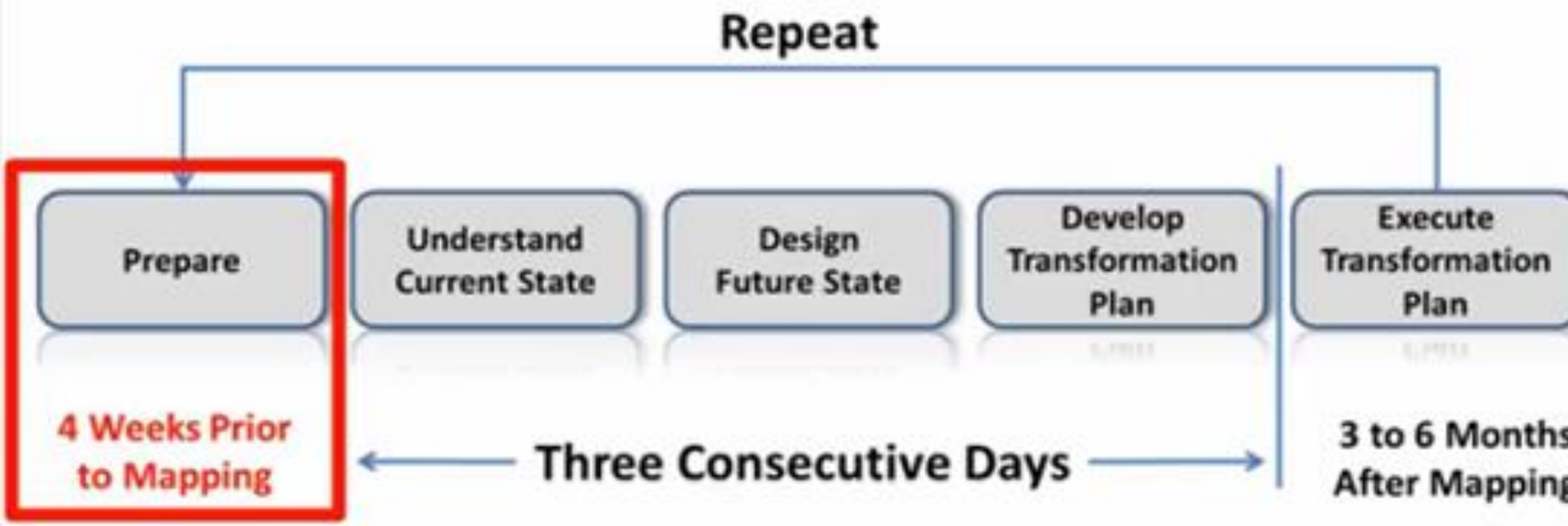
Parallel steps on the timeline



Multiple timelines



Value Stream Mapping Activity Phases and Timing



Current State Map

Drawing the Current State Map

- ✓ Always collect current state information while walking along the actual pathways of material (transaction) and information flows yourself
- ✓ Begin with a quick walk along the entire door to door value stream
- ✓ Begin at the shipping end of the work stream
- ✓ Bring your stop watches and do not rely on standard times or information that you do not personally obtain.
  - Possible exceptions (machine uptime, scrap rate/ rework rate etc)
- ✓ Map the whole stream yourself
- ✓ Always draw by pencil

Paper Airplane Factory

Example of Current State Value Stream Map

Customer Requirements

- 48 planes in 15 Min
- Planes to be defect free, in case there is a defect then customer has to be asked whether this can be shipped
- The material shipped by the supplier
- Paper supplier supplies material in batches of 20 only
- Number of workers at each workstation: 2

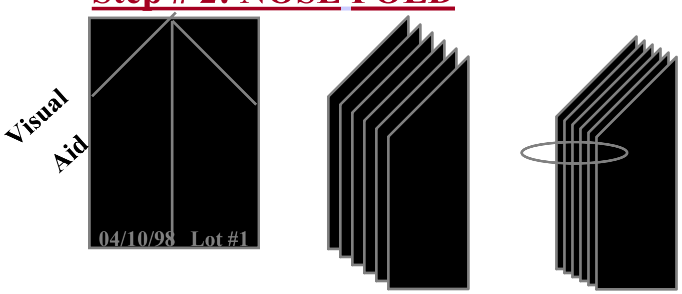
Work done at each Workstation

Supplier supplies raw material only in batches of 20

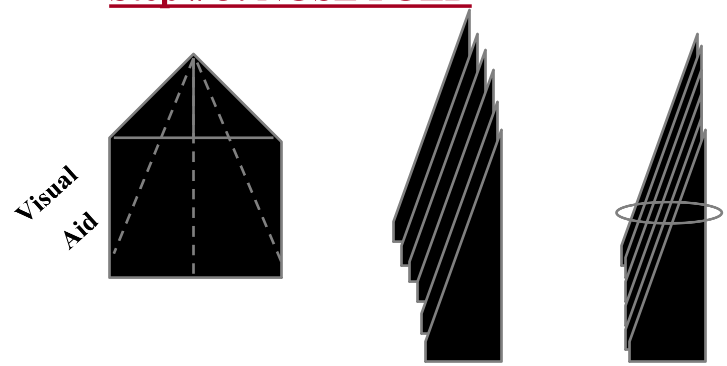
MATERIAL IDENTIFICATION

Step #1: FUSELAGE FOLD

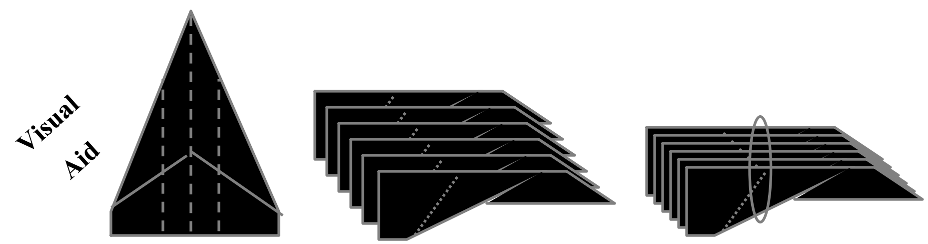
Step # 2: NOSE FOLD



Step # 3: NOSE FOLD



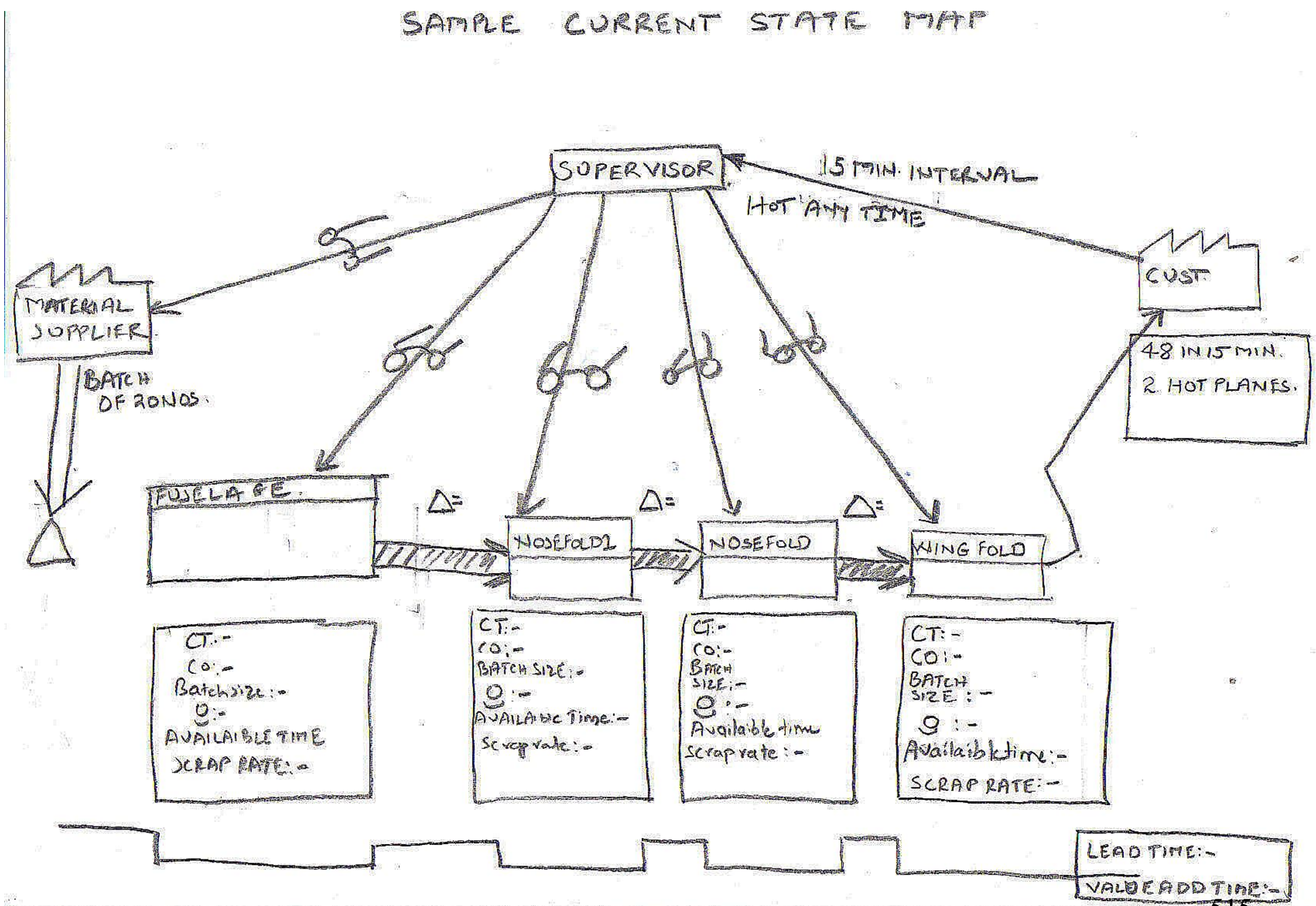
Step # 4: WING FOLD



Note

The images exhibit the production of a 6 piece Batch

Finished current state Map



Key point

- Value stream mapping uses Seconds rather than Minutes for cycle times and all other calculations

Note the Inventory

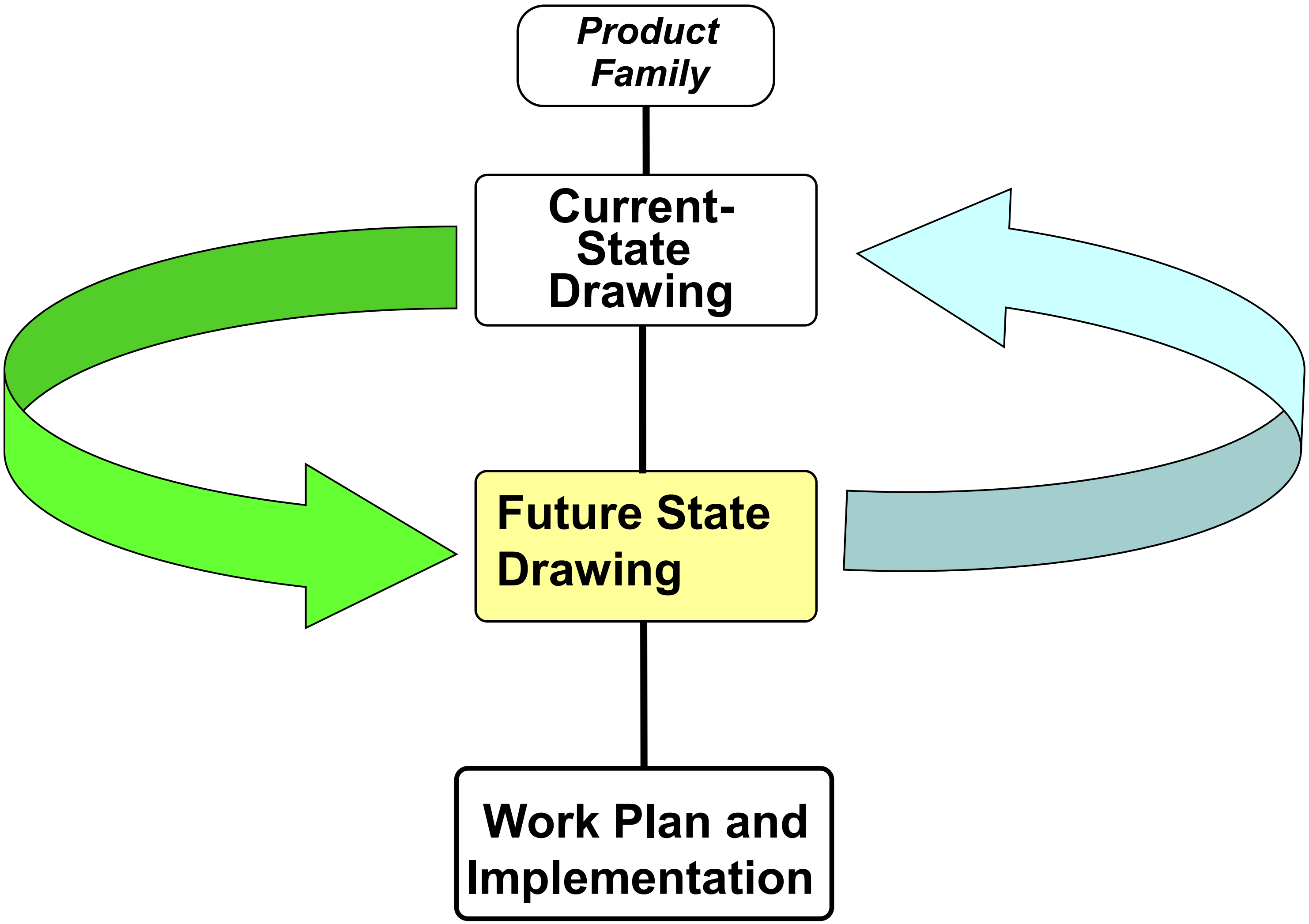
- As you walk the products material flow note the places where you find the inventory
- Use the inventory symbol for such locations
- If inventory accumulates in more than one location between two processes draw a triangle for each location

Push vs Pull

- To qualify as a pull in a services environment subsequent transaction should not be moved to the next person till the next person has accepted the transaction processed earlier
  - This may be achieved through system controlled movement of files between people or
  - This may be achieved through physical bins laid between staff

E.2 Creating the Future State Map

Steps in Value Stream Mapping



Takt Time

The word takt has German Origins

The word takt is taken from the German, which means rhythm of music. Takt time determine how fast a process needs to run to meet customer demand. It is about having a rate of processing that meets the rate of sales.

$$\textit{Takt Time} = \frac{\text{Net available working time per day}}{\text{Customer demand per day}}$$

Net available working time per day is total work time minus meetings, breaks, lunch and other non value added activities.

Example

In a financial service company, there is a demand for 500 credit cards per day. What is the takt time of the process? Assume that the cards are processes in one shift every day and the duration of a shift is eight hours, of which 30 minutes is devoted to breaks, lunch and meetings

$$\textit{Takt Time} = \frac{(8-\tfrac{1}{2})\text{ hr x 60 min x 60 seconds}}{500}$$

$$\textit{Takt Time} = \frac{27{,}000}{500} = 54 \text{ seconds/ unit}$$

This means one card needs to be processes every 54 second to meet the customer demand.

Takt time and Cycle Time

Takt Time - How often do we need to complete one transaction

Cycle Time – How much Total time do we take to complete one transaction

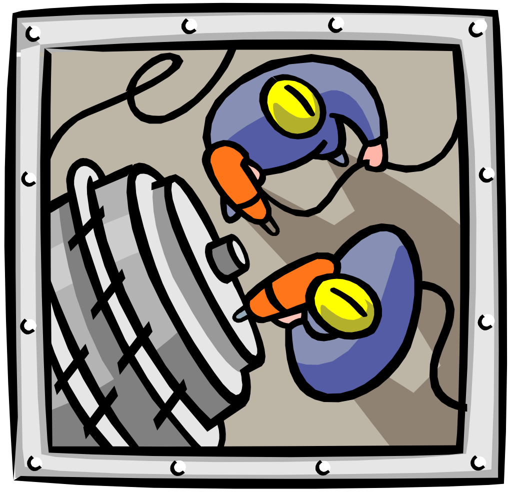
$$\textbf{Headcount} = \frac{\textbf{Cycle Time}}{\textbf{Takt Time}}$$

How many operators are needed to meet Takt?

Remainder in # of operators calculation (after paper Kaizen)	Guideline / Target
<0.3	Do not add extra operator, further reduce waste and incidental work
0.3 - 0.5	Donot add extra operator yet, after two weeks of cell operation and kaizen, carefully evaluate if enough waste & incidental work can be taken out
≥0.5	Add an extra operator if necessary and keep reducing waste& incidental work to eventually eliminate the need for that operator in that cell

Example (cont‟d)

- How to calculate Headcount?



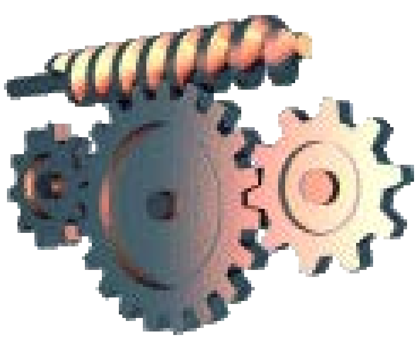
$\frac{\text{34 sec cycle time}}{\text{18 sec takt time}}$ = 2 workers needed

- **This is how resources are properly allocated to meet customer demand:**
  - Anymore workers than 2 = Over production
  - Any less than 2 workers = Not meeting customer demand

SMED

段取り時間の短縮をする

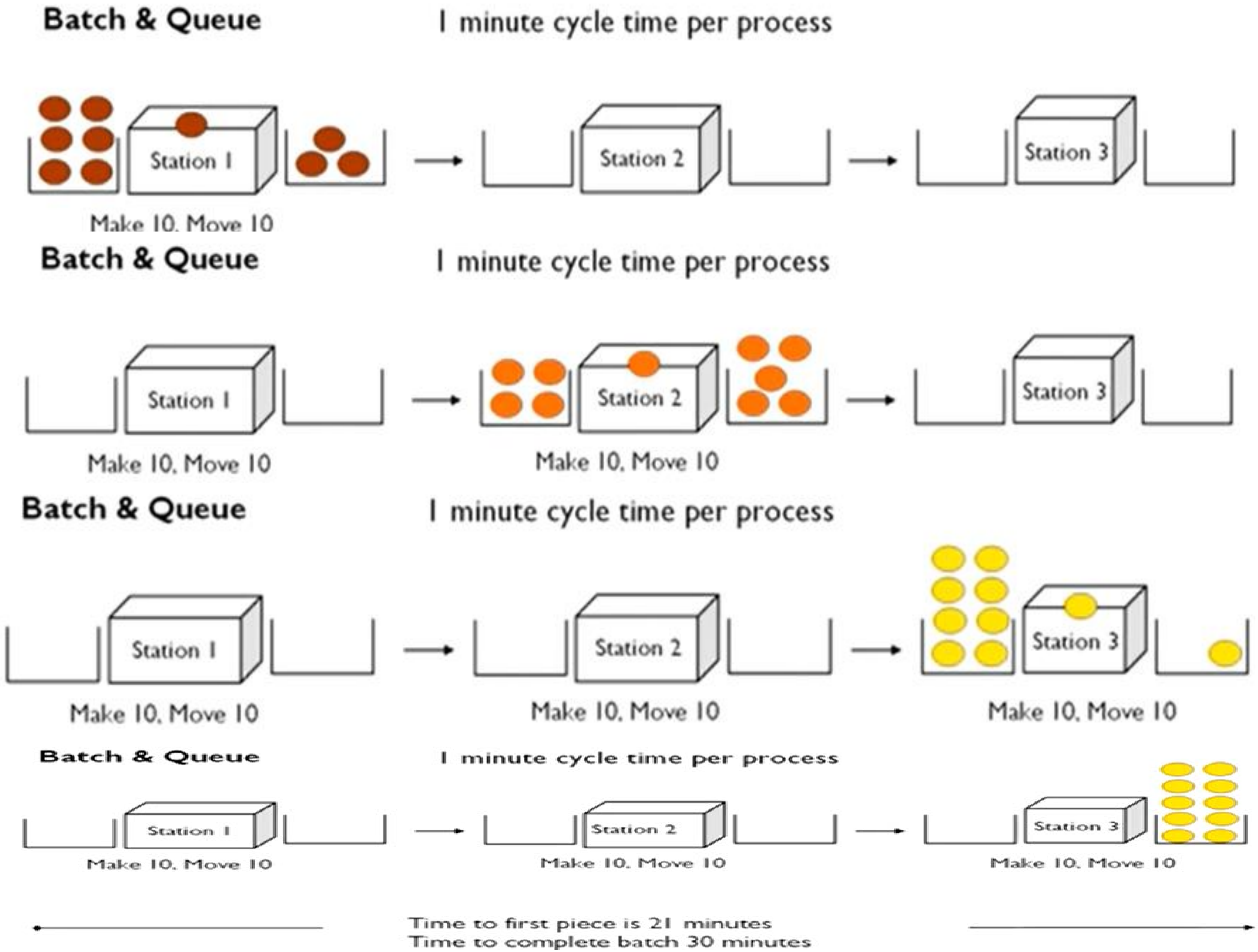
(Set-Up Reduction)

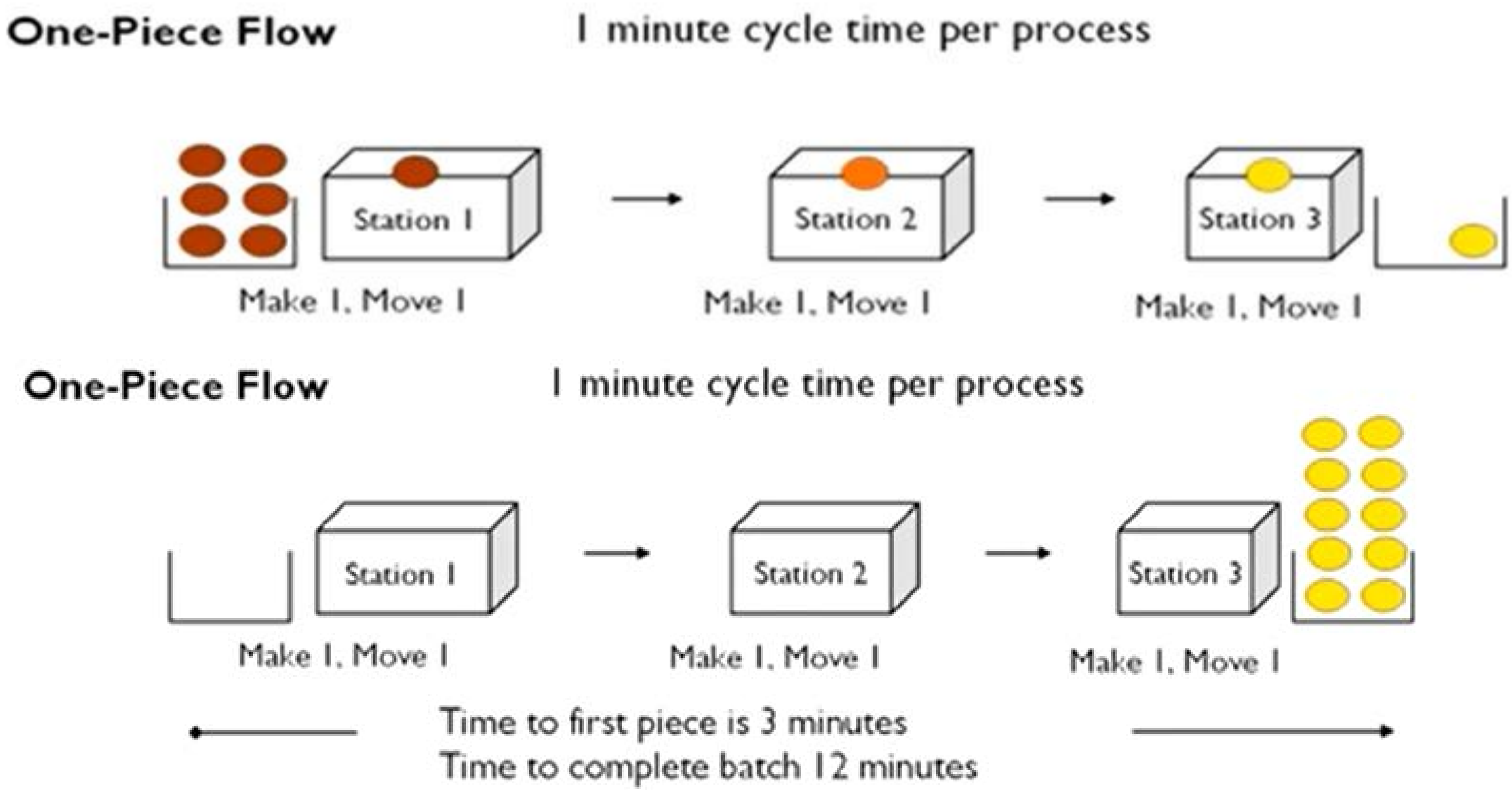


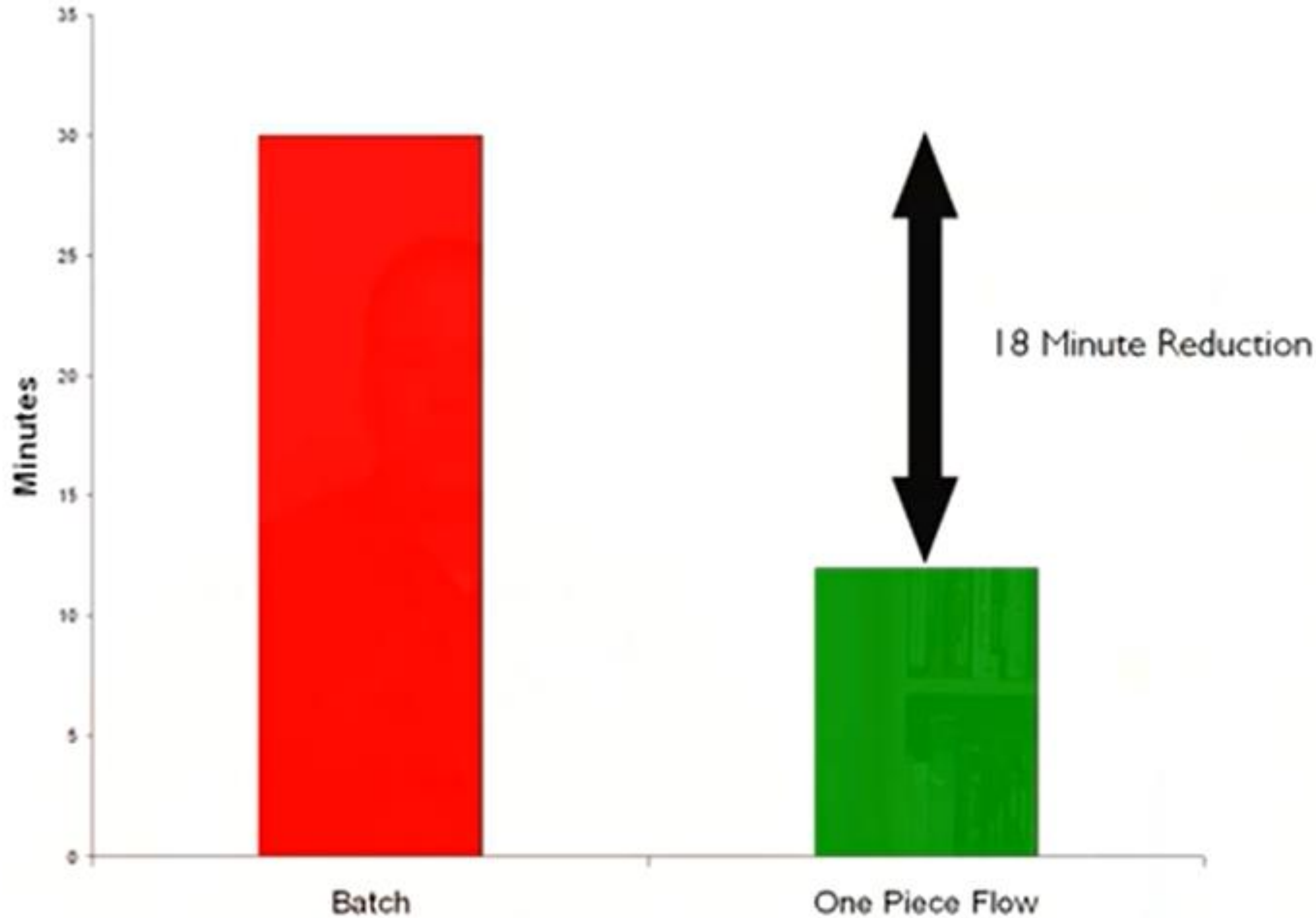
Single Minute

Exchange of Dies

Batch to Single Piece Production




One-Piece Flow
1 minute cycle time per process
Station 1
Station 2
Station 3
Make 1, Move 1
Make 1, Move 1
Make 1, Move 1
One-Piece Flow
1 minute cycle time per process
Station 1
Station 2
Station 3
Make 1, Move 1
Make 1, Move 1
Make 1, Move 1
Time to first piece is 3 minutes
Time to complete batch 12 minutes


35
30
25
20
15
10
5
0
Minutes
18 Minute Reduction
Batch
One Piece Flow

Overview-

In this presentation we will discuss the following questions and learn how to use SMED for continuous improvement. Through a *"Kaizen Event"-(Change for the Better)* we will improve.

- What is **SMED**?
- Why is it important?
- Where should it be used?
- How do we use it?
- How do we sustain it?
- Who is responsible?
- Where do we go from here?

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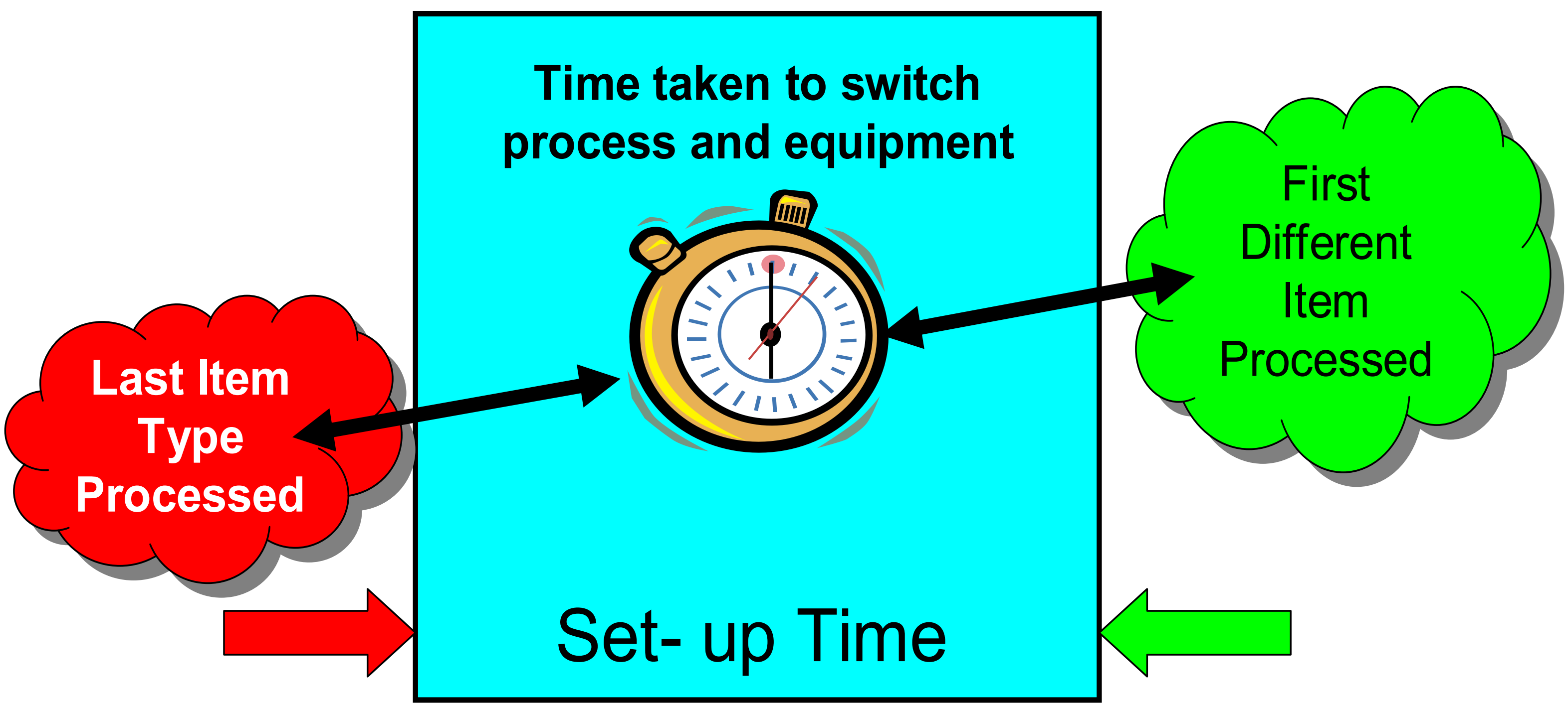
What is SMED? *Single Minute Exchange of Dies*

- SMED ***(Changeover Reduction)*** is a tool supporting Lean Manufacturing. It is used to control and decrease downtime due to changeovers.
- SMED supports the concept of continuous improvement through the removal of waste.
- SMED will make the job more structured, repeatable and easier.
- SMED will take care of our **Customers** better than we do today.

What is SMED? *Single Minute Exchange of Dies*

- SMED is about increasing productivity by decreasing the time from the last good product to the first good product.

„Set-up Reduction"



Where did this come from?

- Developed in the 50‛s 60‛s by Shigeo Shingo, chief engineer of Toyota
  - » Land costs in Japan were very high, not feasible to store large inventories of vehicles
  - » Quick Changeover provided a solution to the common large batch sizes
  - » More importantly, there is nothing new here, all common sense things, once we change the way we look at inventory.

Shingo's Success

1. "A Revolution in Manufacturing: The SMED System"

2. Toyota, using his techniques, reduced setup time from days to three minutes

When is the Changeover Complete?

1. Running product A

2. Downtime = Muda or Waste

3. Running product B

Why Quick Changeovers?

1. Quick changeovers reduce lead time

2. Increase overall velocity

3. Machines only create value when they are running and not sitting idle

Why Quick Changeovers?

1. Reduce lot sizes

2. When lot sizes are reduced, the customer's lead time is also reduced

3. This is because most of the lead time is waiting (queue time)

Quick Changeovers Reduce Inventory

Fast changeovers greatly reduce the need for inventory buffers

Improves On-Time Delivery Performance

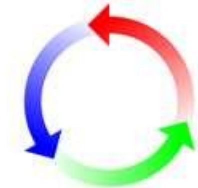
Removing the non-value added time results in the customer getting their product sooner

The Customer

Why is SMED important?

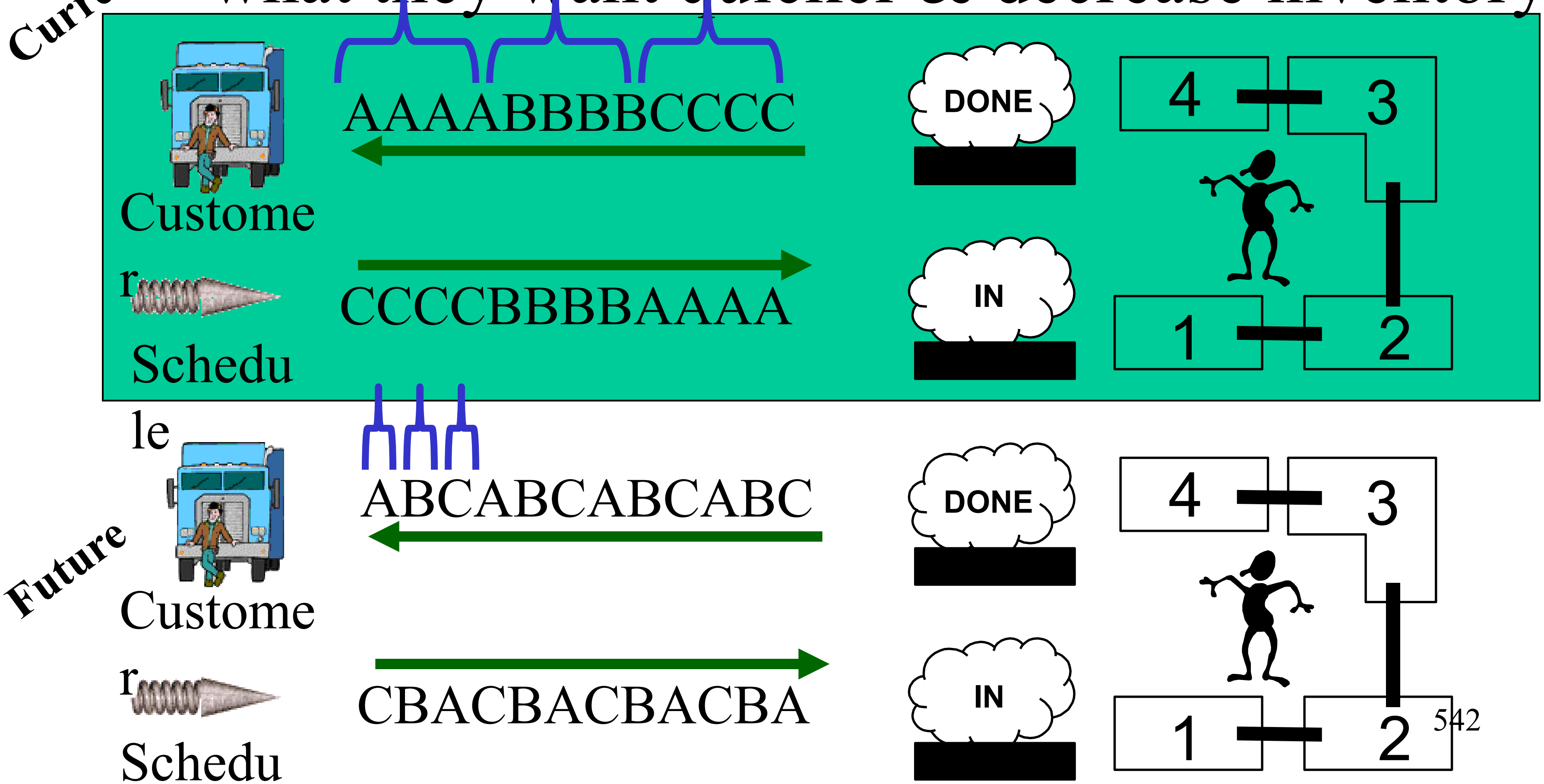
- Reducing set-up time helps us to better serve our customer needs.
  - **Decreases lead time**
    - Smaller batch sizes
  - **Increases flexibility**
    - Growth opportunities
  - **Increases "Customer On Time" delivery**
    - Get product when they want it
  - **Supports** *Takt Time-(Time a product takes to meet a demand-cycle time)*
    - Run to Customer demand not standard
  - **Allows us to keep all Customers happy**
    - Each Customer gets what they want

Why is SMED important?



Cycle Time

- Better able to provide all customers with what they want quicker & decrease inventory.



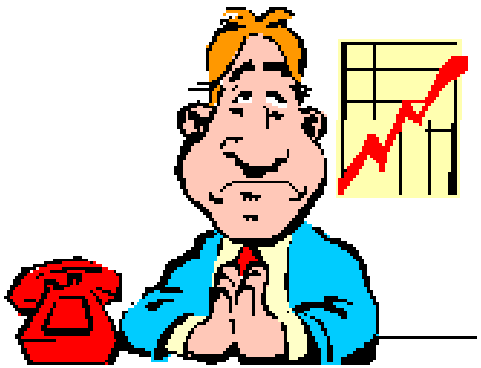
Why is SMED important?

- Think how would you handle your own household.
- Would you buy a weeks worth of groceries or a months worth at a time. Why?

1. Money-Cash Flow
2. Space-Inventory
3. Don‟t need so much-Buy when needed
4. Perishable-Obsolete

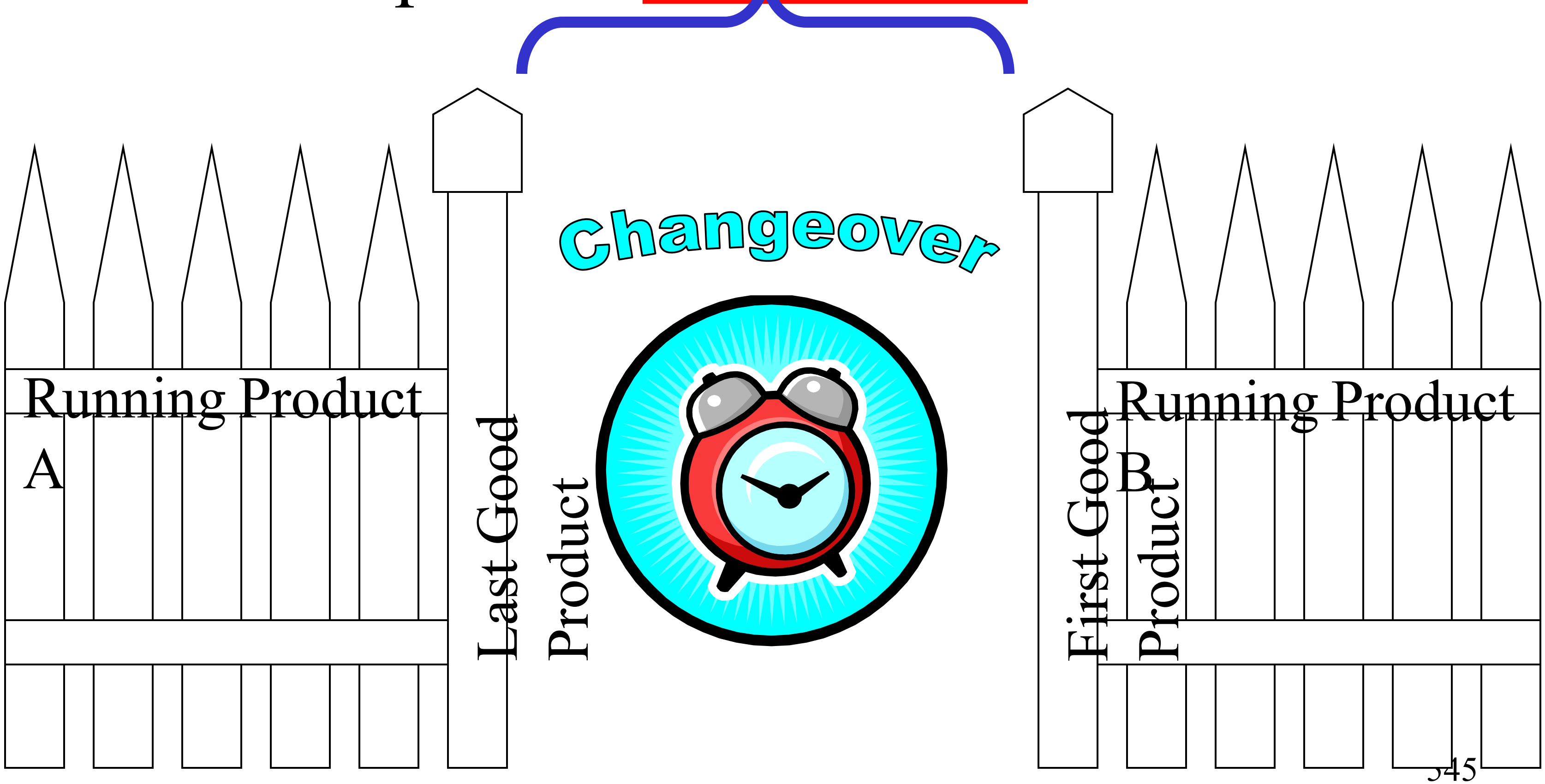
Why is SMED important?

- Line down time is costly. We need shorter changeover time.
- We are losing money when the line is down.
  - Increases profit
  - Increases uptime
  - Creates capacity
  - Creates space in the warehouse
  - Increases flexibility
  - Reduces cost per unit
  - Makes it easier for the operator to change over
  - Easier to train new operators
  - Keeps **all** Customers happy



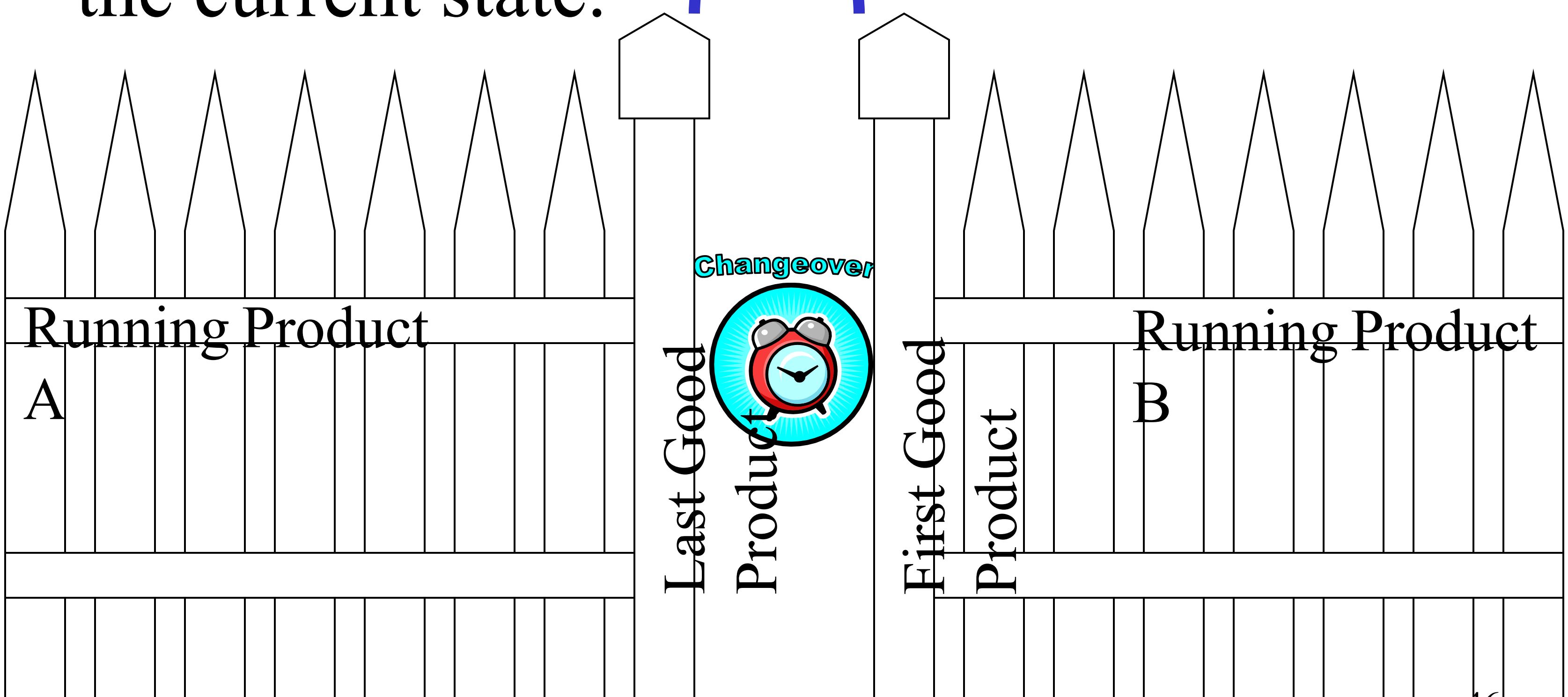
How do we use SMED?

Define set-up & set ***"Fence Posts"***



How do we use SMED?

- Set a goal of at least a **50% reduction** from the current state.



7 Steps to Implementing SMED

Step-1

1. Observe the current methodology
   - Watch a full changeover at least once – more is better
   - Videotape is best

How do we use SMED?

- Videotape the area and then review the video recording with the team and document the **"Current State."~** ***Initial Set-Up Time***
  - Capture the steps used in the changeover.
  - Document waste as it is observed.
  - Stay focused on the current state. (Fence Posts)
  - Try not to jump ahead to improvement ideas.
  - If the video is unclear, visit the area *("Gemba-Work Place")* to gain a better understanding of the steps involved.

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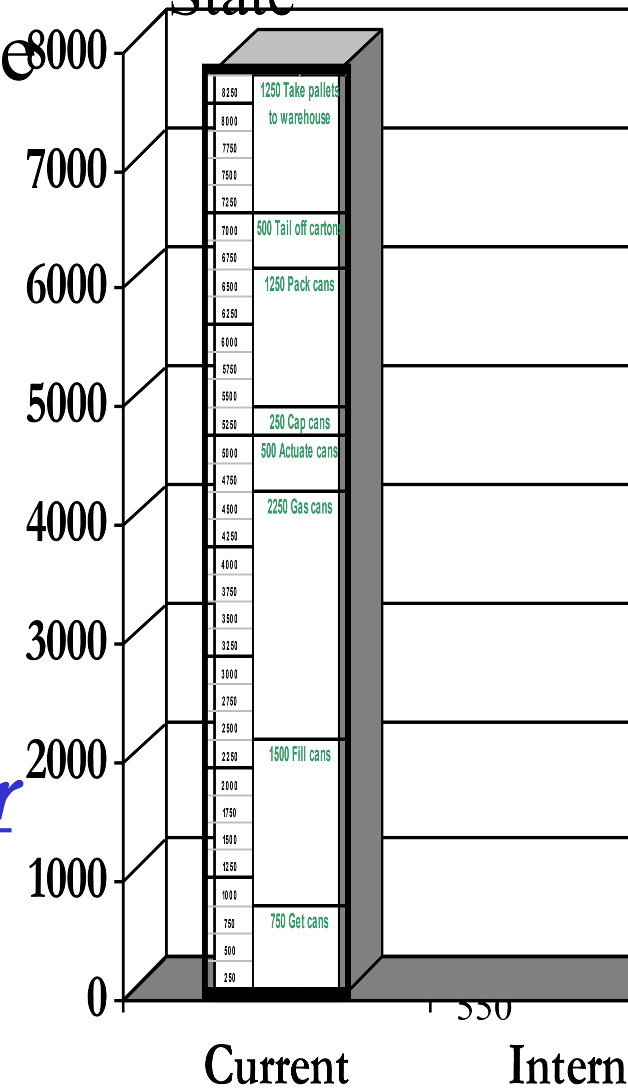
How do we use SMED?

- Use the video to perform time observations.
  - List each step as you observe the video.
  - Capture the time for each step & the total time.
  - Capture walk & waiting times separately (This will help with later steps).
  - Observe waste in the process and make notes.
  - Total time from each step should equal the total time of the changeover.
  - List each step on large easel paper. Have three columns to the right for Takt time, Total time and Pro Forma of each step.

How do we use SMED?

Document the Current State

- Create a Bar Chart to illustrate the current state.
  - Show each step and the time it takes.
  - Try to stay proportional when building the chart.
  - Use the chart as a base line to measure improvements.
  - **This is the *Current State Bar Chart.***



Step 2

2. Separate the *INTERNAL* and *EXTERNAL* activities. *Internal activities* are those that can only be performed when the process is stopped, while *External activities* can be done while the last batch is being produced, or once the next batch has started. For example, go and get the required tools for the job BEFORE the machine stops.

Step 3

3. Convert (where possible) *Internal activities* into *External ones* (pre-heating of tools is a good example of this).

How do we use SMED?

Internal

External

- **Move internal steps to external steps.**
  - **Internal** steps are those steps that take place when the machine has gone down for the changeover. **(We are not making money)**
  - **External** steps are those steps that can be done either before the machine has gone down or after the machine has started up. **(We are still making money)**

Aerosol Changeover Setup Checklist Line 5

PRODUCT:					Shift:		Date:	C/O Time:	
SFO#				ATI# :			Concentrate# :		
STEP	I	E	Communication					Y/N	C/A Required
1		E	Notify Formulation 90 min. prior to C/O (Radio ready)						
2		E	Notify An-Lab 90 min. prior to C/O (Radio Ready)						
3		E	Notify PQA 90 min. prior to C/O						
4		E	Notify Material Handler 90 min. prior to C/O						
5		E	Filler Operator has established Radio Contact with Formulations						
	I	E	Machine	Component #	Pre staged	Operator	Changeparts Verified	Tools Present	C/A Required
6		E	Depal				N/A		
7		E	Filler, Valves						
8		E	Gasser/Crimper						
9		E	Checkweigher/Coder	N/A	N/A		N/A	N/A	
10		E	Tipper						
11		E	Capper						
12		E	Case Erector						
13		E	Case Packer	N/A	N/A				
14		E	Tailoff/Case Coder				N/A	N/A	
15		E	Case Taper				N/A	N/A	
16		E	Tube Taper					N/A	
17		E	Stickers				N/A	N/A	
18		E	Other				N/A	N/A	
	I	E	Machine	Bench Mark	Average	Actual C/O Time	C/A Required		
19	I		Depal		14				
20	I		Filler	38+Flush	72				
21	I		Valves	10					
22	I		Crimper						
23	I		Gasser	26+Gas	77				
24	I		Checkweigher/Coder		13				
25	I		Tipper	27	52				
26	I		Capper	26	57				
27	I		Case Erector	15	43				
28	I		Case Packer		58				
29	I		Bundler						
30	I		Tailoff/Case Coder/Taper		13				
31	I		Other		20				
	I	E	Machine	Changepart stored properly	Changepart repair required		Assigned To		Status Check Complete
32		E	Depal						
33		E	Filler, Valves						
34		E	Gasser/Crimper						
35		E	Checkweigher/Coder	N/A					
36		E	Tipper/Hand Actuate						
37		E	Capper						
38		E	Case Erector						
39		E	Case Packer/Hand Packer						
40		E	Tailoff/Case Coder/Taper	N/A					
41		E	Tube Taper						
42		E	Stickers	N/A					
43		E	Other						
Implemented by:									

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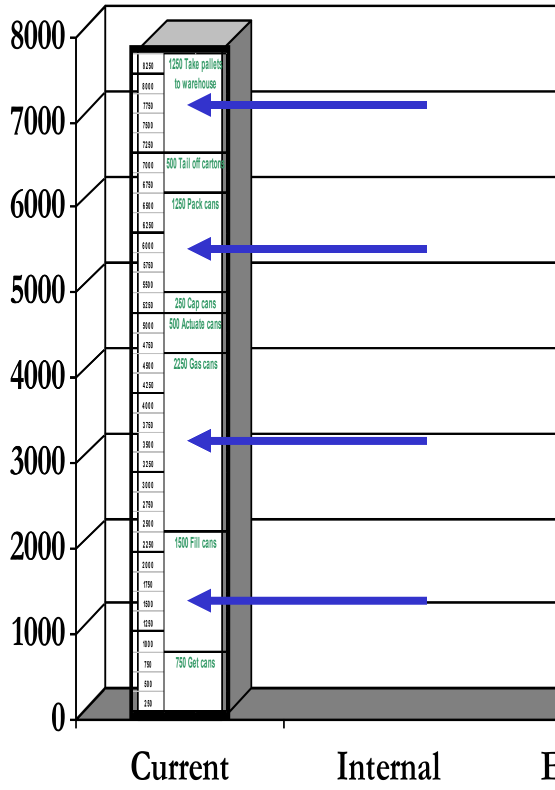
How do we use SMED?

Internal
External

- Separate Internal from External activities. Move Internal to External.
  - **Internal-** *What has to be done when the machine is down.*
  - **External-** *What can be done while the machine is still running.*
- Eliminate adjustments- *"Poka Yoke"-Error Proofing*
- Kaizen- *("Change for the Better")* Internal activities and 5S External activities.
- Eliminate Set-Up. (Tools, blocks, gauges, markings)

Brainstorming Ideas

- Look at the waste you observed in the video and brainstorm ideas to remove it.
- Write ideas into action items on colored post-its.
- Target the largest time blocks on the Current State Bar Chart.



Rearrange Steps

Walking- Point of Use

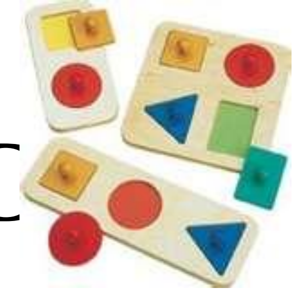
Make Tool-less

Move to External

Different Method

Standardize Bolts

How do we use SMED



Make It Simple

- Eliminate Adjustments
  - Figure out how to turn ***"Adjustments"*** into ***"Settings"***
    - Think about locating holes, stop blocks, color coding, gauges
    - No more tweaking
    - Make the first part a good part every time

Gas Weight Adjustment Matrix for AL4 Gasser

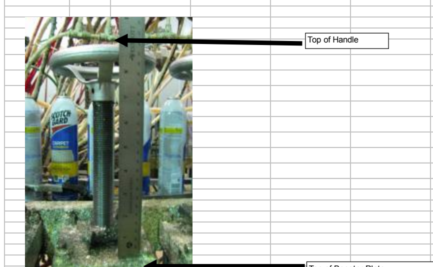
FROM \ TO	Tuff Stuff 22 oz A31 25.2 +/- 2	Tire Foam 18 oz A70/DME 26.0 +/- 2	Tire Shine 18 oz A70/DME 26.1 +/- 2	SOAG 21 oz A70/DME 30.0 +/- 2	Sct. H/W 15 oz A70 42.8 +/- 2	Gumout 16 oz A110 46.5 +/- 2	Gumout 19 oz A110 55.1 +/- 2	Fix-A-Flat 12 oz 134A 88.0 +/- 2	Aqua Net 11 oz DME 91.6 +/- 2	Fix-A-Flat 16 oz 134A 117.5 +/- 2	Fix-A-Flat 20 oz 134A 143.0 +/- 2	3M Dust. 10 oz 152A 287.5 +/- 2
Tuff Stuff 22 oz A31 25.2 +/- 2	_	↑ 0 Turns	↑ 0 Turns	↑ 1/4 Turn	↑ 1 1/4 Turns	↑ 1 1/2 Turns	↑ 2 1/4 Turns	↑ 2 Turns	↑ 3 3/4 Turns	↑ 3 Turns	↑ 3 3/4 Turns	↑ 11 Turns
Tire Foam 18 oz A70/DME 26.0 +/- 2	↓ 0 Turns	_	↑ 0 Turns	↑ 1/4 Turn	↑ 1 1/4 Turns	↑ 1 1/2 Turns	↑ 2 1/4 Turns	↑ 2 Turns	↑ 3 3/4 Turns	↑ 3 Turns	↑ 3 3/4 Turns	↑ 11 Turns
Tire Shine 18 oz A70/DME 26.1 +/- 2	↓ 0 Turns	↓ 0 Turns	_	↑ 1/4 Turn	↑ 1 1/4 Turns	↑ 1 1/2 Turns	↑ 2 1/4 Turns	↑ 2 Turns	↑ 3 3/4 Turns	↑ 3 Turns	↑ 3 3/4 Turns	↑ 11 Turns
SOAG 21 oz A70/DME 30.0 +/- 2	↓ 1/4 Turn	↓ 1/4 Turn	↓ 1/4 Turn	_	↑ 1 Turn	↑ 1 1/4 Turns	↑ 1 3/4 Turns	↑ 1 3/4 Turns	↑ 3 1/2 Turns	↑ 2 3/4 Turns	↑ 3 1/2 Turns	↑ 10 3/4 Turns
Sct. H/W 15 oz A70 42.8 +/- 2	↓ 1 1/4 Turns	↓ 1 1/4 Turns	↓ 1 1/4 Turns	↓ 1 Turn	_	↑ 1/4 Turn	↑ 1 Turn	↑ 1 1/2 Turns	↑ 2 3/4 Turns	↑ 2 1/2 Turns	↑ 3 Turns	↑ 10 1/4 Turns
Gumout 16 oz A110 46.5 +/- 2	↓ 1 1/2 Turns	↓ 1 1/2 Turns	↓ 1 1/2 Turns	↓ 1 1/4 Turns	↓ 1/4 Turn	_	↑ 3/4 Turn	↑ 1 1/4 Turns	↑ 2 1/2 Turns	↑ 2 1/4 Turns	↑ 3 Turns	↑ 10 Turns
Gumout 19 oz A110 55.1 +/- 2	↓ 2 Turns	↓ 2 Turns	↓ 2 Turns	↓ 1 3/4 Turns	↓ 1 Turn	↓ 3/4 Turn	_	↑ 1 Turn	↑ 2 Turns	↑ 2 Turns	↑ 2 3/4 Turns	↑ 9 3/4 Turns
Fix-A-Flat 12 oz 134A 88.0 +/- 2	↓ 4 1/4 Turns	↓ 4 1/4 Turns	↓ 4 1/4 Turns	↓ 4 Turns	↓ 3 1/4 Turns	↓ 3 Turns	↓ 2 1/2 Turns	_	↑ 1/4 Turn	↑ 1 Turn	↑ 1 3/4 Turns	↑ 8 1/4 Turns
Aqua Net 11 oz DME 91.6 +/- 2	↓ 4 1/2 Turns	↓ 4 1/2 Turns	↓ 4 1/2 Turns	↓ 4 1/4 Turns	↓ 3 1/2 Turns	↓ 3 1/2 Turns	↓ 2 3/4 Turns	↓ 1/4 Turn	_	↑ 3/4 Turn	↑ 1 1/2 Turns	↑ 8 Turns
Fix-A-Flat 16 oz 134A 117.5 +/- 2	↓ 6 1/4 Turns	↓ 6 1/4 Turns	↓ 6 1/4 Turns	↓ 6 Turns	↓ 5 1/4 Turns	↓ 5 1/4 Turns	↓ 4 1/2 Turns	↓ 1 Turn	↓ 1 1/2 Turns	_	↑ 3/4 Turn	↑ 7 Turns
Fix-A-Flat 20 oz 134A 143.0 +/- 2	↓ 8 Turns	↓ 8 Turns	↓ 8 Turns	↓ 7 3/4 Turns	↓ 7 Turns	↓ 7 1/4 Turns	↓ 6 1/2 Turns	↓ 1 3/4 Turns	↓ 3 Turns	↓ 3/4 Turn	_	↑ 6 Turns
3M Dust. 10 oz 152A 287.5 +/- 2	↓ 17 1/2 Turns	↓ 17 3/4 Turns	↓ 17 3/4 Turns	↓ 17 1/2 Turns	↓ 17 1/4 Turns	↓ 18 Turns	↓ 17 1/2 Turns	↓ 6 1/4 Turns	↓ 11 Turns	↓ 5 1/4 Turns	↓ 4 1/2 Turns	_

= Adjust Down (Turn Clockwise) = Adjust Up (Turn Counterclockwise)

Handle Height In Inches (Measure From Top of Booster Plate to Top of Handle)

	DME	A31	A46	A70	A70/DME	A110	134A	152A
10	141	115	114	109	114	101	xxx	191
9	121	99	98	94	98	88	xxx	164
8	101	83	82	79	82	73	xxx	137
7	82	67	66	64	66	60	xxx	110
6	62	51	50	49	50	45	110	83
5	42	35	34	34	35	30	74	56
4	23	19	18	19	19	16	57	29
3	4	xxx	xxx	xxx	xxx	xxx	xxx	xxx

NOTE: 12 turns per 1 inch



Grams per turn	
DME	1.6
A31	1.3
A46	1.3
A70	1.2
A70/DME	1.3
A110	1.2
134A	3
152A	2.2

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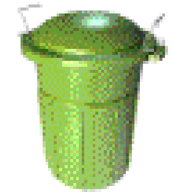
How do we use SMED?



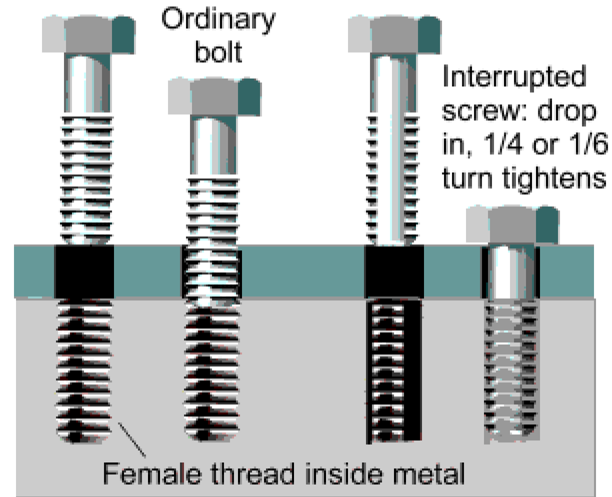
"Muda"

Wasteful Activity

- Look for the **8 wastes** in the process?
  - **Defects**- Creating WIP *(Work in Progress)* or waste
  - **Overproduction**- Too much, too early
  - **Waiting Time**- Waiting for something before continuing
  - **Non-Utilized Talent**- Damage to people
  - **Transportation**- Moving people or materials
  - **Inventory**- Accumulation of product to be worked
  - **Motion**- Unnecessary human movement (Turning, twisting, bending, taking steps, etc…)
  - **Extra Processing**- Non value added to the process

7 Steps to Implementing SMED

4. Streamline the remaining *Internal activities*, by simplifying them. Focus on fixings - Shigeo Shingo rightly observed that it's only the last turn of a bolt that tightens it; the rest is just movement.



1. Only the final turn on a bolt adds value
2. The interrupted screw (or interrupted thread) provides one means of clamping and unclamping something quickly. Artillery breeches have been sealed in this manner since the nineteenth century.

7 Steps to Implementing SMED

5. Streamline the *External activities*, so that they are of a similar scale to the *Internal ones*.

7 Steps to Implementing SMED

6. Document the new procedure and the actions that are yet to be completed.

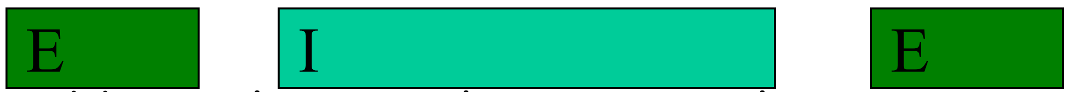
7 Steps to Implementing SMED

7. Do it all again: For each iteration of the above process, a 45% improvement in set-up times should be expected, so it may take several iterations to cross the ten-minute line.

How do we use SMED?

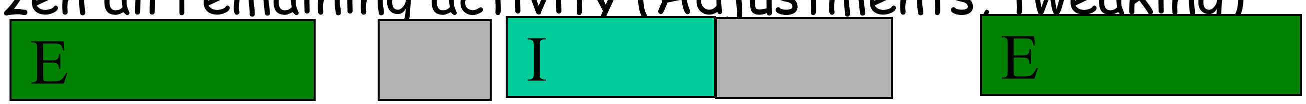
1. Current State

2. Separate full steps to internal and external activity

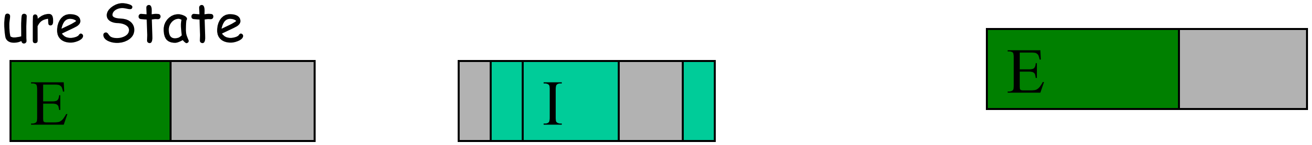


3. Convert additional internal to external activity

4. Kaizen all remaining activity (Adjustments, tweaking)



5. Future State



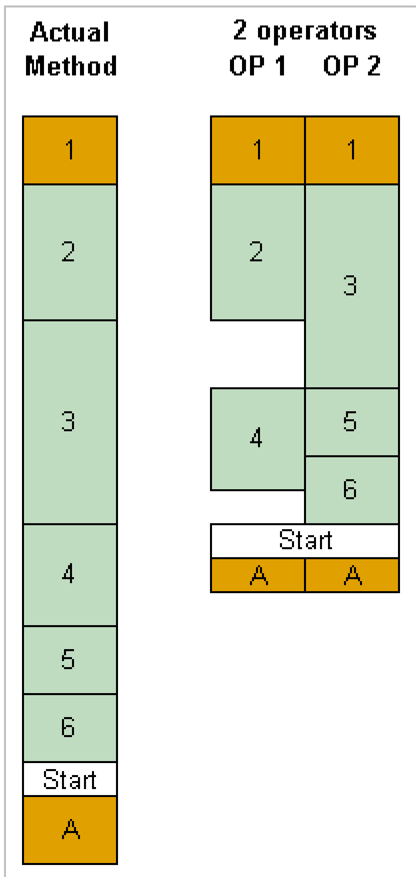
Target 50% Improvement

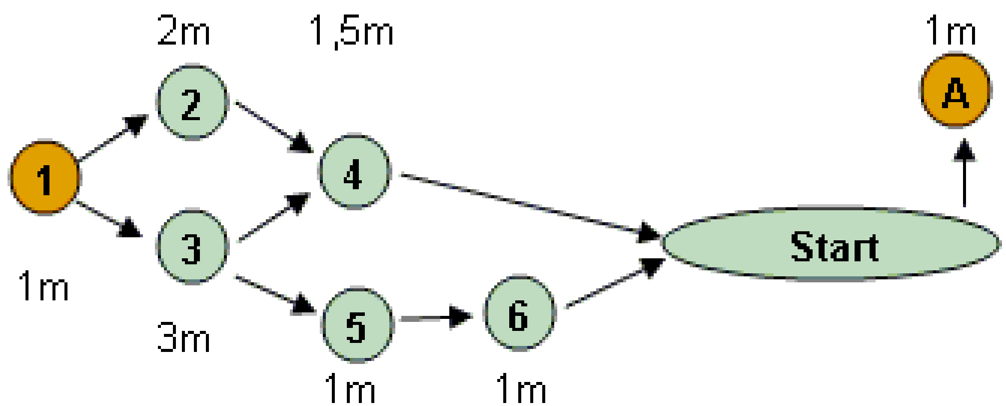
Parallel Operations Using Multiple Operators

Level load the changeover

Balance the tasks

Teamwork - Parallel Operations Using Multiple Operators





Tollgate - Measure

- Detailed As-is Process Map
- Specifications & Defects
- Data Collection Plan
- Sampling Plan & Sample Size
- GRR for the measurement system
- Process Capability
- Lean